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New technologies on road freight transport in Spain

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Abstract

One of the main actual challenges that the transport and planning sector has to face is the improvement of its energy and economic efficiency. In this issue, road transport has been improving its efficiency through different solutions, as new engines, better tires, less emissions and many other developments.

The aim of this project was to introduce Longer and Heavier Vehicles (LHV), commonly known as MegaTrucks, as an alternative to road freight transport. A description of these new vehicles was given as well as the actual situation in Europe. Focusing more in our own case, the first part of the work includes an overview on all Spanish regulation. Furthermore, the actual situation in terms of costs and benefits was studied with a supposed scenario including MegaTrucks. It was possible to see that the introduction of MegaTrucks would imply some benefits to private companies, but the percentage of saving varies a lot depending on the conditions of the trip.

The second part of this project focused on road safety regarding MegaTrucks. From an individual point of view, the individual safety of a LHV might be lower but, at the same time, benefits regarding collective road safety might appear. For instance, fewer vehicles on the road at the same time as less total emissions are some beneficial issues for society.

At the end, a simulation tool was used to predict the change in user behaviour when driving together with MegaTrucks. The results stated that the impact on collective road safety is neutral while there are some economic benefits for the private investors and government.

This paper tries to summarize the main important effects from LHV towards the road network and its users.

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1. Introduction and goals

One of the main actual challenges that the transport and planning sector has to face is the improvement of its energy and economic efficiency. In this issue, road transport has been improving its efficiency through different solutions, as new engines, better tires, less emissions and many other developments.

Regarding the environmental sector, the European Legislation of Transport has become more exigent within the last years for larger energy efficiency, with less contaminant engines and less pollutant emissions for human health.

In this aspect, the increase of the gross vehicle weight rating (GVWR) or gross vehicle mass (GVM) of trucks (MMA – Masa Máxima Autorizada in Spanish) allows the operator merging loads and, thus, reducing the number of vehicles required for the transport of goods.

The capacity of road vehicles is an essential factor regarding the cost of transport. The legislation has been changing through the last years adapting to the needs of transport companies so that the maximum weight and dimensions have been increasing progressively.

European directive 96/53/EC from 29th April 2015 restricts and stablishes the value for weight and dimensions of the vehicles intended to freight transport in an international context. However, each country can give permission to the circulation of vehicles that exceed these values in national transport, always inside the border of the country.

In Spain, around 83% of the total tonnage corresponds to national transport, while 79,9% of this national transport resembles to road freight transport. At this point is where the implementation of longer and heavier vehicles (LHV – longer than 18,75 meters and heavier than 44 tonnes) commonly known as MegaTrucks takes place. The use of LHVs in certain conditions may result in economic, social and environmental benefits. By contrast, rail freight transport decreased from 4,8% to 3,3% in the last years, while other means of transport, such as inland waterways, are negligible. Given this current unbalance, all the measures focused to increase efficiency of road freight transport can produce larger benefits than any marginal measure motivated in any other type of transport.

The market requirements for private companies regarding the adoption of these vehicles are clear: it must be a lower transportation cost, improved logistical service and improved competitiveness. From the government view, the traffic safety must remain the same or improved where possible, while the emissions to the atmosphere must decrease together with noise pollution and congestion.

There had been various studies regarding this topic. Many of these studies concluded that MegaTrucks could bring numerous benefits to society, while only some of them, particularly the ones carried out by companies against LHVs stated a different opinion. Mainly, the majority of the studies concluded that the use of MegaTrucks would end up with a lower number of vehicles – kilometre with approximately the same amount of tonnes transported. Nevertheless, all previous studies were mainly focused on economy and potential benefits with this implementation, and their results differ significantly from each other depending on who did the study.

The aim of this project is to introduce MegaTrucks as an alternative to road freight transport. A description of these new vehicles will be given as well as the actual situation in Europe. Focusing more in our own case, the first part of the work is an overview on all Spanish regulation. Furthermore, the actual situation in terms of costs and benefits will be compared with a supposed scenario including MegaTrucks.

The second part of this work is to provide an overview to collective road safety on the network. The collective road safety in a Spanish highway will be evaluated and compared with the actual situation by means of a simulation tool, PTV VISSIM 8. Taking real data from national statistics will be a key factor for trusting the results obtained.

At the end, not only it will be possible to give an answer to the economic and social benefits of LHVs but also to state if the collective road safety is affected by its implementation, a key factor due to the fear of the people towards this new technology.

2. Definition of Longer and Heavier Vehicle

Nowadays, conventional trucks on the road have a length of 16,50 meters and a weight of 40 tonnes to circulate across European borders (see next section for old Spanish regulations). In many countries such as Spain or France, for intermodal traffic, heavier vehicles up to 44 tonnes are implemented. However, to talk about LHV (Longer and Heavier Vehicles), the length should be increased up to 18,75 meters and the weight more than 44 tonnes. There are many possible configurations for these especial vehicles; indeed, the most common configuration for MegaTrucks has a nominal length of 25,25 meters and a maximum total weight of 60 tonnes. In figure 2.1 it is possible to observe a comparison between this configuration and conventional cars.

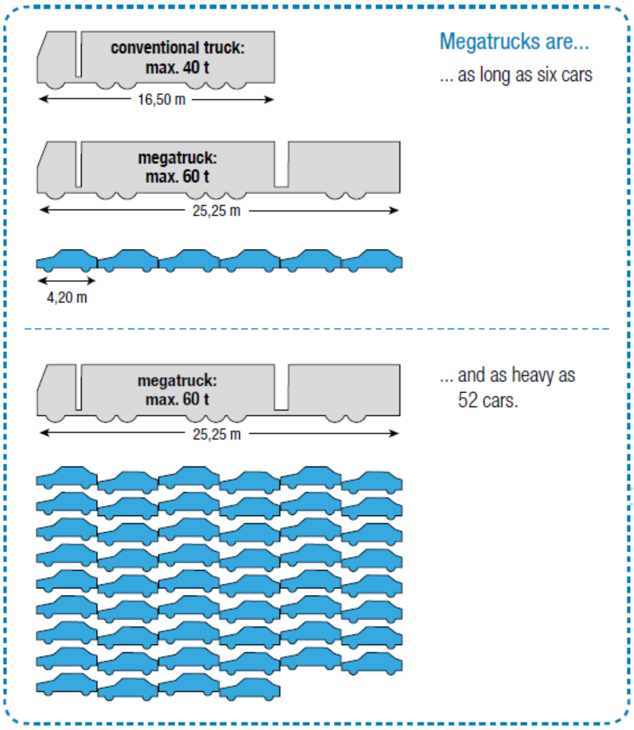


Figure 2.1 - Comparison between cars and LHV
Source: MegaTruck vs rail freight, UNIFE, CER, UIC

As said above, many configurations are possible. Even some configurations have the same length and weight, some differences in their behaviour can be found depending on the number of axis and semi-trailers. Below a brief introduction of the different configurations is given.

2.1 Configurations of MegaTrucks:

The different configurations were developed and studied carefully mainly in the northern countries. The dimension of vehicles in the EU directive follows the modular system, a principle that subdivides a system into smaller parts (European Modular System – EMS). This system defines 6 main single parts that can be combined with each other to form and create a MegaTruck. The parts, as it is possible to observe in the image below, are the Tractor, Semi-trailer, Semi-trailer with 5th wheel, Truck, Dolly and Centre-axle trailer.

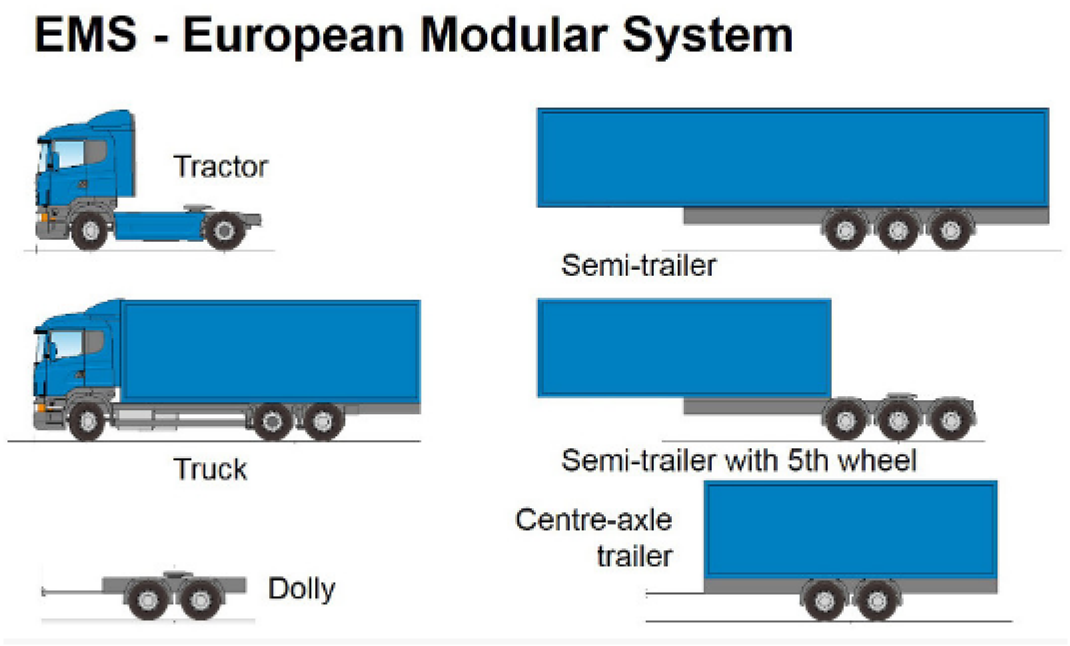


Figure 2.2 – Single parts of the European Modular System
Source: Scania trucks

An LHV can enter the maximum length of 25,25 meters composed of several standard vehicle components. The EU directive also includes the rules for the dimensions of each component and its maximum cargo. The following list (from A to E) describes and gives an overview of the current configurations studied in real roads in The Netherlands:

A. Tractor + Semi - Trailer + Centre axle trailer

“A” configuration consists of a tractor with a semi – trailer and a centre – axle trailer. The semi – trailer has a length of 13.60 meters with the centre – axle attached just behind it. This configuration has 2 rotation points, also coinciding with the coupling points, named plate coupling (between the tractor and the trailer) and drawbar coupling (between the trailer and the centre– axle trailer).

Figure 2.3 - Configuration A
Source: CROWnl

B. Tractor + Semi - Trailer with 5th wheel + Semi - Trailer

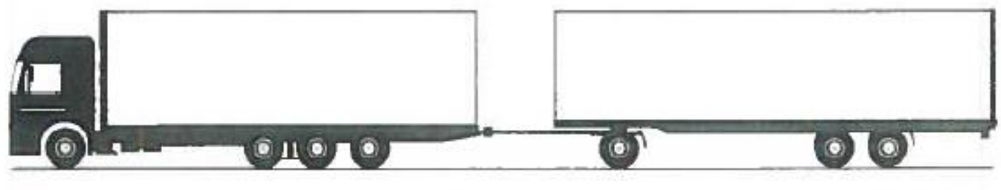
B

This configuration consists of a towing unit, a tractor to which in this case a semi – trailer is coupled and another longer semi – trailer attached to the previous one. The total combination is intended to be designed in the event of transporting 3 containers with a length of twenty feet (TEU).

Figure 2.4 - Configuration B
Source: CROWnl

C. Truck + Semi - Trailer

C



The “C” configuration consists of a long truck with a trailer. This configuration is hardly used in practice since it only uses a portion of the additional load length. In the test time, this configuration was not studied at all, reason why no pictures are included.

D. Truck + dolly axle + Semi - Trailer

D

“D” configuration consists of a truck coupled with a dolly axle with semi – trailer. The dolly can be provided with one or with double axel. During the test period, this configuration was by far the most common and most used.

Figure 2.5 - Configuration D
Source: CROWnl

E. Truck + two centre axle trailers

E

The “E” configuration consists of a motor vehicle coupled with two centre axle trailers. The combination is often used to transport outlet boxes (which can be detached from the vehicle quite easily when needed).

Figure 2.6 - Configuration E
Source: CROWnl

The modular system implies that different configurations for LHV are possible at the same time. In the tests performed prior to the experience, configuration “D” was the most used by transporters (63 out of 100 experiments were performed with this configuration). On the other hand, configuration C was not used at all. In between, configuration A was studied in 16%, B in 14% and E, 7%.

In table 2A the different configurations of LHV are summarized and compared in table 2B in terms of general behaviour with actual conventional trucks:

Table 2.1 – Configurations of LHV

		vehicle concept[23]	gross vehicle weight
1		6 x 4 lorry with semi-trailer on dolly (25.25 m)	60 t
2		6 x 4 lorry with two drawbar trailers (25.25 m)	60 t
3		B-Double, tractor with interlink semi-trailer + semi-trailer (25.25 m)	60 t
4		4 x 2 tractor with semi-trailer and drawbar trailer (25.25 m)	48 t
5		4 x 2 tractor with longer semi-trailer of 14.92 m (17.8 m)	40 t
6		not yet defined future option with length of 25.25 m	40 t

* Not in use yet, future option with 25,25 meters and 40 tonnes.

Source: Transport & mobility Leuven, “*Effects of adapting the rules on weights and dimensions of heavy commercial vehicles*”, 2009.

Table 2.2 – Impact on road safety of different configurations

Vehicle \ Maneuver	Weight	Roundabouts	contouring	Lane change		maneuverability
				Soace	tilt	
		Behaviour				
1	60t	↗	↗	↘	↗	↘
2	60t	↗	ϟ	↓	ϟ	↘
3	60t	↗	↗	↘	↗	↘
4	48t	↗	⬊	⬊	↓	↘
5	40t	↗	↗	↗	↗	↗
6	40t	Further investigation is necessary				

↗	Similar or better behavior than a conventional truck
↘	Slightly lower behavior than a conventional truck
⬊	Worse behavior than a conventional truck
↓	Clearly adverse behavior than a conventional truck
ϟ	Unacceptable

Source: Transport & mobility Leuven, "*Effects of adapting the rules on weights and dimensions of heavy commercial vehicles*", 2009.

All scenarios were depending on the configuration, being as a general rule the ones with semi-trailers the best ones.
As a result of all these configurations, the loading capacity for a transport vehicle is increased up to 39 tonnes.

Table 2.3 – General properties of MegaTrucks

	Conventional truck	MegaTruck
Maximum length	18,75 meters	25,25 meters
Maximum authorised weight	40 tonnes	60 tonnes
Unloaded vehicle weight	15 tonnes	21 tonnes
Maximum load	25 tonnes	39 tonnes (57% increase)
Load capacity	33 pallets *	52 pallets

*33 Pallets considering volume limitation

Source: own elaboration

2.2 MegaTrucks in Europe

In Europe, some sectors that feature goods such as timber, gravel, stone and many other aggregates, paper, steel and petro-chemicals were visibly asking for a change of the freight road system. Here, the need of Larger and Heavier Vehicles has been clearly evident for these sectors. However, the fact that has fuelled recently the high interest in studying these vehicles in the area of general cargo is the reorganisation that Europe conducted by leading the multinationals trading across the regions. The unification of boundaries in 1993 and the adoption of the Euro as a common currency in 2000 have led European countries to expand their interests.

One consequence of this is the development of "focused factories" where the production of manufactured products is consolidated on one site to get the maximum profit to economies of scale. Also, road transport is usually the preferred service to supply and help large chains due to the fact that is the most flexible mode of transport being able to operate door to door. All these factors have clear implications on the demand for the adoption of Larger and Heavier Vehicles as large volumes of goods produced need to be transported away over long distances to hub points over Europe.

Actually, European law (Directive 96/53/EC) states that road vehicles crossing international borders must not be longer than 18,75 meters and weightier tan 40 tonnes. In some cases the weight can be increased up to 44 tonnes if the transport is part of a combined journey. However, each member country is free to set its own national regulations inside its own borders. Until June 2012 there was no option for MegaTrucks to cross any border. Since then, European Commission for transport stated that LHV could cross the border between two countries as long as both countries accept the use of this kind of vehicles in their own legislation.

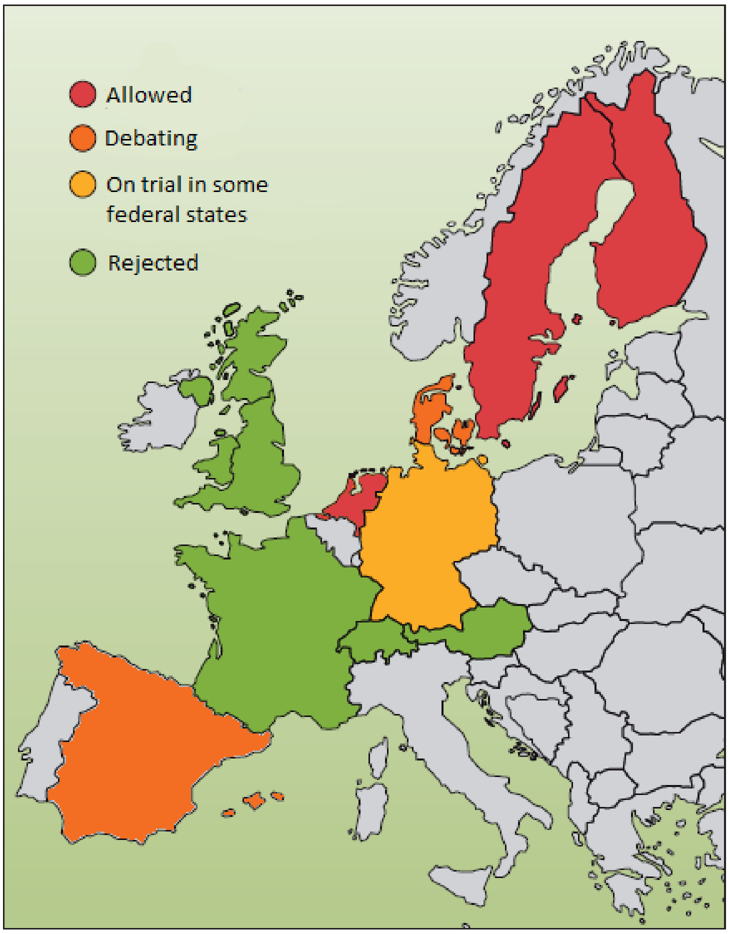


Figure 2.7 – Use of LHV in Europe
Source: UIC, CER, "*Mega – camiones frente transporte por ferrocarril*", 2014 and own elaboration

In the following lines the different European regulations in different countries regarding MegaTrucks are indicated:

2.2.1 Sweden:

The circulation of vehicles up to 25,25 meters and 60 tonnes is allowed since 1995. Exceptionally, longer vehicles are allowed with the required permission.

In 2008 the project "*En Trave Till*" was proposed. This particular project studied the feasibility of allowing vehicles up to 30 meters and 90 tonnes. "*The aim of the project is to change the Swedish load limit legislation to allow vehicle combinations of up to 90 tonnes and 30 metres in length instead of today's 60 tonnes and 25 metres. Driving with a 50% larger load increases efficiency and cuts carbon emissions by 20% compared with a traditional timber vehicle combination"* (Volvo Trucks prolocutor, 2010). Nevertheless, in 2015 this project was still in development, so such vehicles are not clearly allowed yet.

At the beginning of the use of MegaTrucks, Swedish governed proposed a new system for taxes for every truck (independently of their weight) on the road in order to recollect money for improving the quality of the roads. With this new tax it was possible to collect around 400 million of Euros.

Since these vehicles are allowed for almost 21 years, Swedish governed was able to perform many studies. In Sweden, fuel consumption decreased around 14,3% which lead to a diminution of CO_2 emissions. It was estimated that without this type of vehicle 14.000 extra tonnes per year (+25%) of NO_x would be thrown in the atmosphere.

2.2.2 Finland

Finish government has a similar regulation to Swedish: Trucks up to 25,25 meters and 60 tonnes are allowed. Several studies performed together with Sweden proved that a larger length improves energy efficiency around 20% and its consequent saves of CO_2. Due to specific geographic and demographic conditions, Finland and Sweden were the firsts countries where MegaTrucks where approved. Long road distances, low density of population and a limited infrastructure were factor which allowed its implementation. From that moment, several countries with totally different characteristics started to perform studies regarding this issue and its introduction to the road freight transport.

2.2.3 Norway

In 2009 a pilot project with duration of three years started. In this project some roads connected with Finland and Sweden were studied under the circulation of MegaTrucks.

These vehicles were not allowed in other type of routes which not met the requirements of the project. However, after the trial period no clear regulation is written yet.

2.2.4 The Netherlands

The use of MegaTrucks has been studied in The Netherlands in three different periods under strict conditions as a part of tests phases:

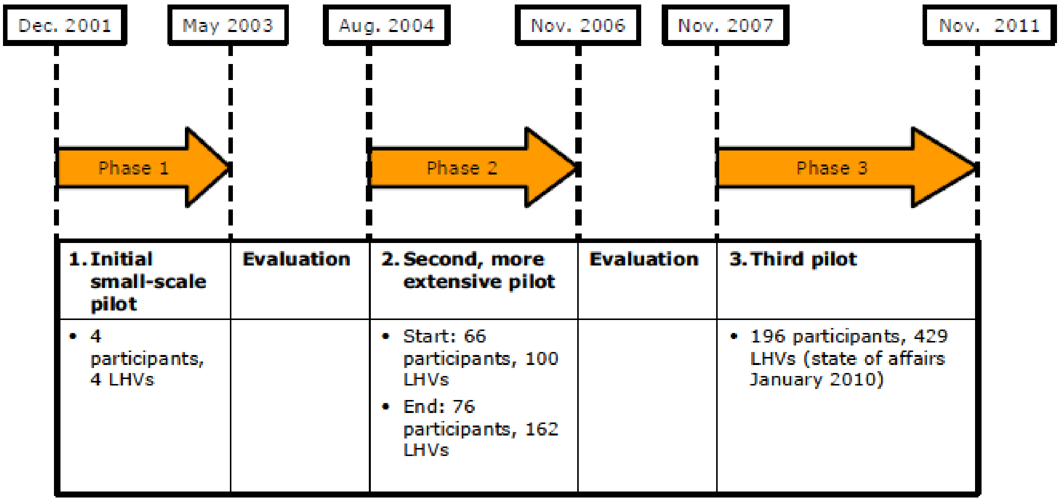


Figure 2.8 – Timeline of the use of LHVs in The Netherlands
Source: Rijkswaterstaat, "*Longer and Heavier Vehicles in The Netherlands*", 2010

The first trial period took place from December 2001 and May 2003. During this small-scale period of approximately one and a half year, four transport companies were allowed to use LHV.

The second period was more extensive and took place between August 2004 and November 2006. In contrast with the first period, in this test 76 companies were involved in the study with a total number of 162 LHVs.

The third pilot for the implementation of MegaTrucks started on November 2007. The Netherlands agreed to allow longer vehicles up to 60 tonnes as a part of a new program called "*Experience phase*". This phase ended in November 2011, after studying the effects of an increase of the number of LHVs on Dutch roads.

During this "*Experience Phase*", concretely in 2009, the use of MegaTrucks in Holland increased exponentially. At the beginning of this pilot only a number of 109 companies were taking part in the experiment, a number that grew up to 190 transport companies. Also, the total number of Longer and Heavier vehicles increased up to 398 vehicles.

The conclusions of these trial periods were positive with a reduction of fuel, reduction of operational costs and any further increment of risk accident. In The Netherlands, MegaTrucks are mainly used by supermarket chains, large retailers, floriculture industry and container transport.

2.2.5 Denmark

Following the Norwegian example, in 2008 a three year trial period started. In September 2010, the Danish government accepted to extend the circulation of vehicles of 25,25 meters and 60 tonnes until 2017. The government invested 11,4 millions of euros to adequate intersections and roundabouts. Any company in the transport sector can join this initiative.

Figure 2.9 – Main Danish allowed routes for MegaTrucks in the project
Source: Martin, Roggerman, "*No MegaTrucks campaign*"

2.2.6 Germany

In October 2007, due to a big debate between the new regulations regarding the weight of the vehicles for freight transport the trial project was stopped. Next year, in 2009, a new project which allowed a length of 25,25 meters but a maximum weight of 40 tonnes started again. With the 2009 federal elections, the national government was interested on a nationwide trial of MegaTrucks, but 16 Länden (federal states) rejected to take part in any trial phase.

After this federal failure, it became a constitutional challenge with a decision yet pending.

2.2.7 France

The use of MegaTrucks is completely forbidden due to differences between their roads. There is a heterogeneity conflict with their bridges, which approximately 9% were constructed before 1940. From January 2011 the maximum weight is limited to 44 tonnes for agricultural goods.

2.2.8 United Kingdom

In 2008 the UK Department for Transport rejected the proposal of the introduction of MegaTrucks even though an experimental trial had been performed. Actually, the maximum weight remains in 44 tonnes in exceptional cases but not as a general rule.

Other European countries came out directly with a clear decision against the use of Longer and Heavier vehicles. Countries such as Switzerland or Austria followed the British example with a clear rejection.

2.3 International between countries

As exposed above, The Netherlands is one the few countries where the circulation of MegaTrucks is allowed. According to several interviews realized by Dutch government, over 70% of interviewed LHV companies indicated that they would use MegaTrucks for the transport of international goods if this would be permitted (the actual relation does not allow these vehicles to cross international borders). Even thought, some companies that were currently not using LHVs stated that they would study its adoption in their services if the internationalisation would be a real fact.

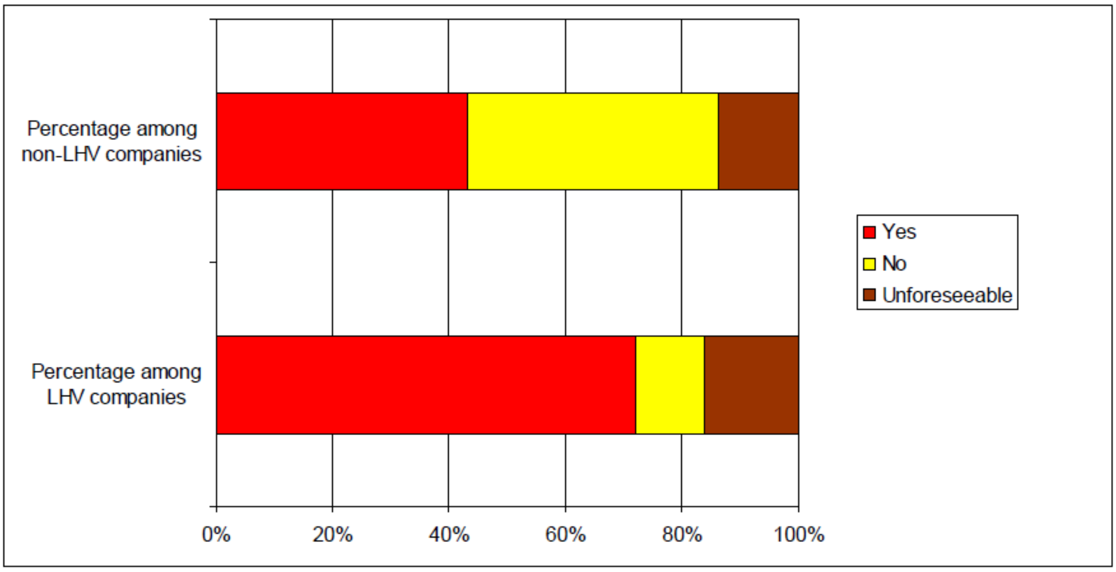


Figure 2.10 – Do you think you will use LHVs internationally if this option presents itself? LHV survey (118 LHV companies, 51 non-LHV companies)
Source: Rijkswaterstaat, "*Longer and Heavier Vehicles in practice*", 2011

Not every country in Europe will allow a maximum weight of 60 tonnes. Thus, is not much important to study this hypothetical situation but gain insight in a lower weight category for international transport. However, the results according to the questionnaire from The Netherlands show a completely different behaviour, where many companies would change their offer.

3. Research question

As said briefly in the introduction the aim of this project is to introduce MegaTrucks as an alternative to road freight transport. A lot of studies expose that the benefits clearly overweight the costs involved in the adoption of these new technology.

The first part of this work focus on studying the economic feasibly of these vehicles. In that section all the attention is focused on evaluating all the costs involved with MegaTrucks and compare a future scenario with 30% MegaTrucks (this value of 30% will be explained in detail in section 5) with the actual scenario where only regular trucks are allowed.

The first question to answer is if it is really beneficial for private companies to invest in Longer and Heavier Vehicles or if it is not worth for them. By comparing both scenarios in particular Spanish corridors (Barcelona – Madrid, Valencia – Barcelona and Valencia – Madrid) it will be possible to analyse the factors involved and see the reduction of costs, if any.

However, one of the main controversial issues and highly debated is the safety of those MegaTrucks. Since they are not implemented in many countries, it has been hard to determine whether the accidents on the road have been caused by some intrinsic factors of LHVs or simply for general factors without any relation between larger and longer trucks.

There are few reports done in order to introduce MegaTrucks in our society where the safety risks on the road are included. Among the several studies on this topic, there is consensus that the introduction of those vehicles will lead to a reduction of the total number of vehicles on the road to transport the same amount of goods. Thanks to this reduction of the total number of vehicles, problems and cost per vehicle – km are quite balanced regarding the costs per tonne – km. Nevertheless, the conclusions regarding the collective road safety are not that clearly shown.

As said in the introduction, the second part of this work is to provide an overview to collective road safety on the network. By comparing the actual scenario with a scenario with different percentages of MegaTrucks it will be possible to answer and evaluate whether the adoption of LHVs suppose an extra risk to the collective road safety.

4. Spanish regulations regarding road freight transport vehicles

4.1 Regulations

The growth in freight transport calls on the road market to implement creative solutions, with which the efficiency of such transport can be further increased. Thus, Spanish legislation has been constantly changing to adapt to the needs in each period. In the following table a full review of the different legislations regarding the maximum dimensions of vehicles is given:

Table 4.1 – Overview of Spanish legislation regarding road freight transport vehicles

Year	Legislation	Number of axis	Maximum weight (tonnes)	Physical Dimensions (meters)		
				Length	Width	Height
1962	Decreto 496/1962	More than 3	32	16,50	2,50	4
1967	Decreto 1216/67	More than 3	38	18	2,50	4
1986	Real Decreto 2029/1986	6	44	18	2,50	4
1991	Real Decreto 1317/1991	6	44	18,35	2,50	4
1995	Real Decreto 1467/1995	6	44	18,35	2,50	4
1997	Real Decreto 490/1997	6	44	18,75	2,55	4
1998	Real Decreto 2822/1998	6	44	18,75	2,55	4
2004	Orden PRE/3298/2004	6	44	18,75	2,55	4
2015	Orden PRE/2788/2015	More than 6	60	25,25	2,55	4

Source: Own elaboration with data from *Efecto de la implantación del vehículo de 25,25 y 60 Ton. en España and Boletín oficial del estado (BOE)*

The last modification of Spanish regulation took place 18th December 2015. Since then, the old regulation PRE/3298/2004 was the one in force.

The main important changes have been on the dimensions and the weight of the vehicles. After the last publication, vehicles with more than 6 axis up to 25,25 meters are allowed with a weight up to 60 tonnes (same dimensions as other countries where MegaTrucks are allowed).

> El anexo IX «Masas y dimensiones», del Reglamento General de Vehículos, aprobado por el Real Decreto 2822/1998, de 23 de diciembre, queda modificado de la siguiente manera:
>
> Uno. Se incorpora el punto 1.23 en el apartado 1 «Definiciones», con el siguiente contenido:
>
> «1.23 Configuración euro-modular: Conjunto de vehículos con más de 6 líneas de ejes, cuyos módulos separadamente no superan los límites máximos de masas y dimensiones establecidos en este anexo para el tipo de vehículo que corresponda.»
>
> Dos. Se incorpora el apartado 6 «Masa máxima autorizada y longitud máxima autorizada de los conjuntos de vehículos en configuración euro-modular».
>
> «6. Masa máxima autorizada y longitud máxima autorizada de los conjuntos de vehículos en configuración euro-modular.
>
> Se podrá autorizar por el órgano competente en materia de tráfico, previo informe vinculante del titular de vía, la circulación de conjuntos de vehículos en configuración euro-modular, con una masa máxima de hasta 60 toneladas y una longitud máxima de hasta 25,25 metros por un plazo determinado, en las condiciones que se fijen en la autorización. La carga no podrá sobresalir de la proyección en planta del vehículo. Siempre que sea posible, los itinerarios de estos transportes deberán transcurrir por autopistas y autovías.
>
> No se podrá conceder la autorización a la que se refiere el párrafo anterior cuando se pretenda realizar transporte de mercancías peligrosas por carretera.»

Figure 4.1 – Fragment of the last regulation published by Boletín Oficial del Estado
Source: Boletín Oficial del Estado, 2015

The full publication can be found in Annex 1.

Four months later, on 12th April 2016, the government department that is responsible for the Spanish traffic safety (Dirección General de Tráfico - DGT) fixed the rules that MegaTrucks should follow in order to circulate in Spanish roads:

- MegaTrucks will not be able to circulate on every road: its circulation will be restricted only on highways, motorways and conventional roads with clearly separated pavements for each direction of traffic. They will be only allowed to circulate on conventional roads with only one carriageway when for loading and unloading is necessary its circulation.

  In that case, the regulation says that the loading and unloading points should be located in an industrial zone or logistic centres. Also, traffic authorities have the right of suspend the circulation in these roads if there are adverse weather conditions (minimum visibility 150 meters).

- Maximum speed: MegaTrucks will have a similar regulation regarding maximum speed to conventional trucks. On highways and roadways the speed limit will be 90km/h, 80km/h on conventional roads with safety lane of 1,5 meters or more and 70km/h on the rest of interurban roads.

  Furthermore, it is stated that when MegaTrucks are going to its respective loading and unloading points they will not be allowed to overtake any vehicle faster than 45km/h.

- DGT establishes that MegaTrucks must have light signals V-2 (top – end of the vehicle), V-6 (corresponding to long vehicle), V-23 (contour signalling) and other mandatory light signs corresponding to road freight transport vehicles.

- Authorisation: companies that want to take benefit of these vehicles must request the authorisation to their corresponding province traffic organisation (Jefatura provincial de tráfico) which will be valid for one year. After this period, it is necessary to request its extension.

  Once the authorisation is given, a MegaTruck will be allowed to make any desired trip, but under the condition that the holder must inform DGT about the trip, the number of authorisation and the schedule of the itinerary.

See annex 2 for the full publication.

4.2 First test carried out in Spain:

On April 4th 2016 the first test in Spain took place. The model, a Scania with 580 hp had 25,25 meters length and was loaded until its full capacity, 60 tonnes. The experimental trip in Spain was carried out in the proximities of Barcelona, from the headquarters of Sesé Group to Seat factory, covering only 37 kilometres in AP-7 highway. The location was chosen in a strategic point: due to the high amount of goods going to Europe, AP-7 has the largest density of heavy traffic.

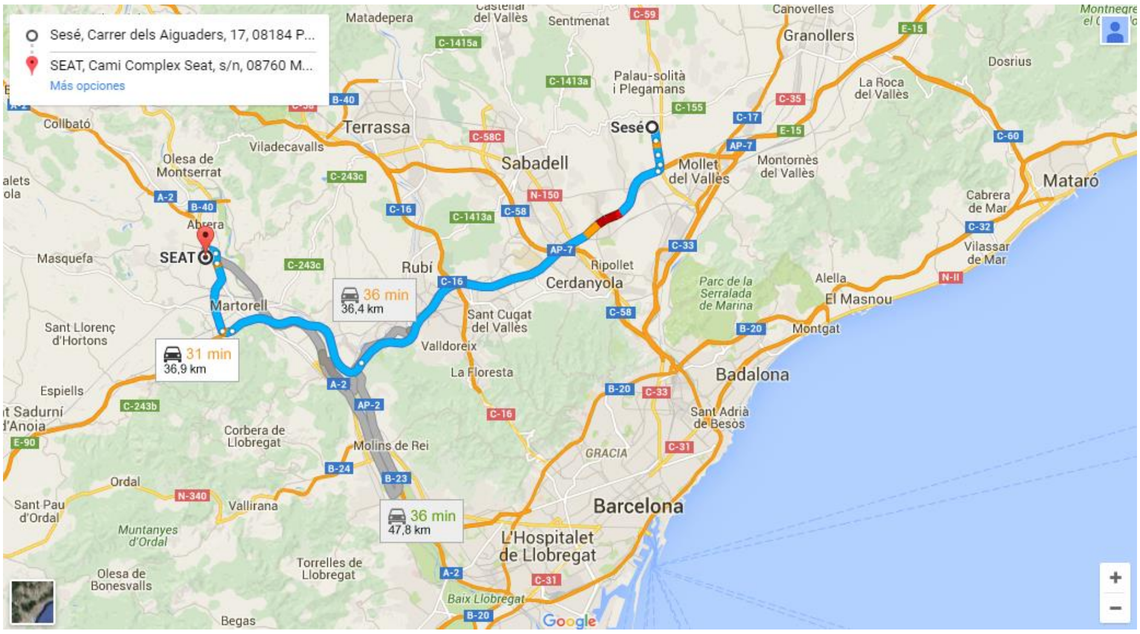


Figure 4.2 – Details of the first trip with a MegaTruck in Spain
Source: Google maps

Figure 4.3 – Image of the first MegaTruck circulating in Spain
Source: Motorpasion.com

According to the previous section, this MegaTruck is composed by a Tractor with a Semi – trailer with 5th wheel which has a length of 7,8 meters and a Semi – Trailer with a length of 13,6 meters. This test resulted in a positive outcome, with a total emission of 48,84g of CO_2. Taking into account the weight of this truck and the length of the trip, it results in 0,022 g/km·tonne, a lower value that the one obtained with conventional trucks.

Figure 4.4 – Image of the first MegaTruck circulating on AP-7 Spain
Source: Motorpasion.com

However, some smaller tests were carried out before this experiment in Spain. Actually, on 14th March 2016 (always after the modification of BOE) PSA Peugeot Citroën group tested in Vigo together with Sesé group the first model of a MegaTruck in Spain. Although this first tests was not as significant as the previous one, also showed large benefits, with a similar radius of curvature and more easiness for loading / unloading thanks to the possibility to disengage each part of the modular system.

5. The freight transport system in Spain

Road freight is in Spain the most used mode of transport, achieving 78,9% of the total tonnes – kilometre registered in the year 2015 (Ministerio de Fomento – 2016). During the period between 1995 and 2008 the number of tonnes – kilometre raised more than 140% mainly as a result of the increment of the total net tonnes transported. Meanwhile, in the same period of time some other sectors such as the rail freight experienced some decrease. This high increase had a large influence on the gross domestic product of the country. In Spain, the GDP value followed the tendency of the tonnes – kilometre, rising from 1995 until 2008.

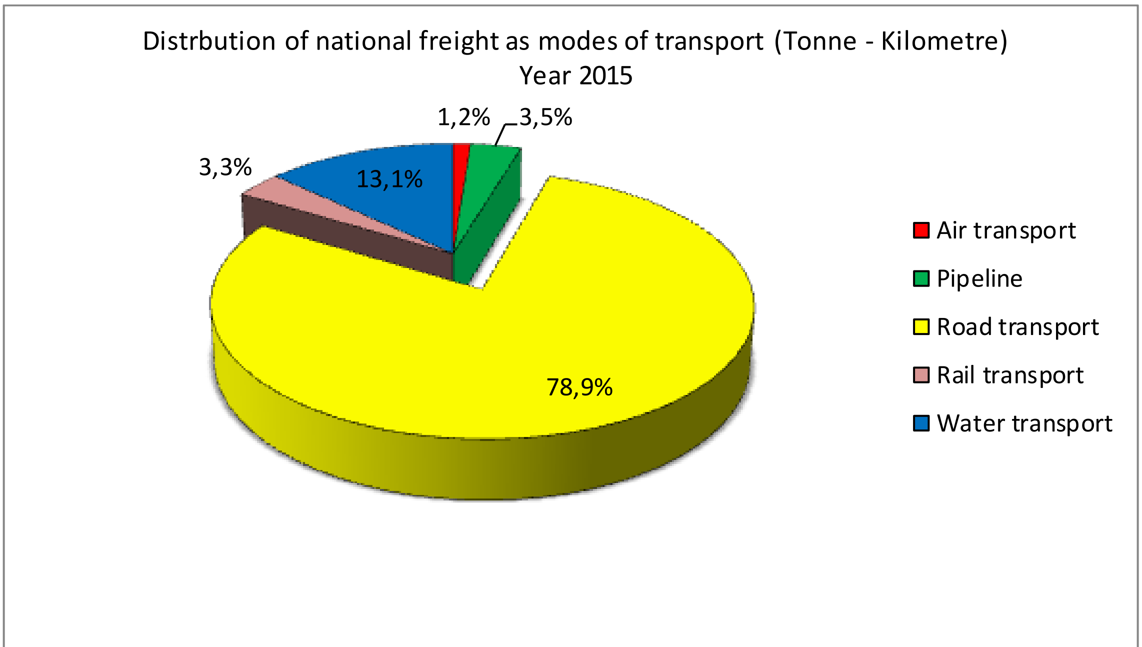


Figure 5.1 - Distribution of national freight as modes of transport (Tonne - Kilometre) in 2005
Source: Own elaboration, with values from Ministerio de Fomento 2016

However, the economic crisis that started in 2008 (that is still present in some countries) stopped this large raise leading to a fall of the total number of vehicles registered for the transport of goods and, therefore, the total cargo capacity able to do so. Nevertheless, the tonnes – kilometre did not experience any significant decrease, a fact that suggests that the transport companies maintained their efficiency being able to transport the same amount of tonnes with less vehicles.

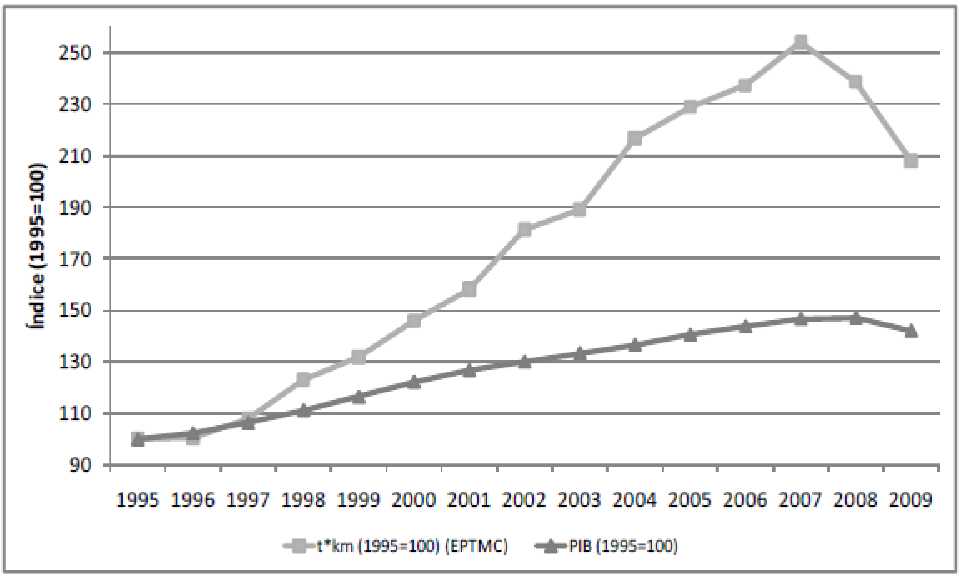


Figure 5.2 – Evolution of road freight transport and Gross Domestic Product
Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España",* 2011

Due to the actual distribution of freight transport, measures focused on the road sector have more potential to produce larger benefits for society and for private investors than the marginal changes in the modal split. This conclusion had been argued and published by TRANSyT in 2011.

For the determination and analysis of the distribution of the heavy vehicles that actually operating in Spain, the data from "Encuesta Permanente de Transportes de Mercancias por Carretera" (EPTMC) from the national Government has been used. The statistics are referred up to the year 2015 since it is the last update with detailed data. As said above, two main periods from 1995 can be distinguished, according to the start of the economic crisis: 1995 – 2008, and 2008 – 2015.

From EPTMC, basic indicators are given such as the total number of tonnes, the tonnes – kilometre or the global operations. From these basic indicators it is possible to obtain other indicators more complex as the content, the average distance or the efficiency of the transport:

$$Distance\ of\ transport = \frac{Tonne - kilometre}{Cargo} = [km]$$

$$Content = \frac{Average\ distance}{Cargo} = \left[\frac{km}{tonne}\right]$$

$$Efficiency = \frac{Tonne - kilometre}{Vehicles - kilometre} = \left[\frac{tonne}{veh}\right]$$

These 3 indicators together with the total number of tonnes – kilometre are represented in the figure below. From the period 1995 – 2009 only the figure is given due to the lack of individualised data. From 2009 until 2015 detailed data is given for each year and presented below.

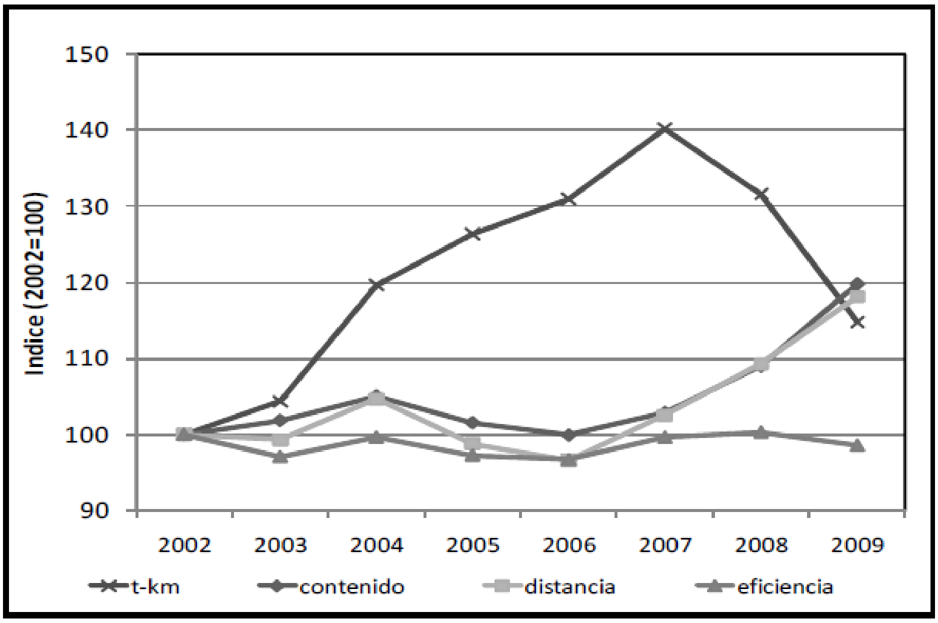


Figure 5.3 – Evolution of indicators in road freight transport in the period 2002 - 2009
Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España",* 2011

As it is possible to observe in the figure, this first decade of the century had a significant raise in Spain.

From the individual analysis it is possible to know the following values for road transport in Spain:

Table 5.1 – Indicators of road freight transport in the period 2009 - 2015

	Tonnes	Tonnes - Kilometre	Global operations	Cargo operations
2015	1.258.748.950	209.386.710.000	178.369.381	101.225.755
2014	1.184.865.860	195.763.410.000	168.672.418	94.981.108
2013	1.124.832.990	192.594.150.000	158.629.005	88.931.099
2012	1.239.139.870	199.205.490.000	174.364.736	97.322.014
2011	1.466.501.640	206.839.880.000	200.825.340	110.407.659
2010	1.566.704.560	210.064.160.000	219.151.457	119.928.523
2009	1.711.314.150	211.890.950.000	238.723.000	129.195.000

Source: Own elaboration, with values from EPTMC

Table 5.2 – Indicators of road freight transport in the period 2009 - 2015

	% empty operations	km Average	Vehicle - Kilometre (global)
2015	43,25	166,3	20.769.609.734
2014	43,69	165,2	19.507.627.098
2013	43,94	171,2	19.012.345.020
2012	44,18	160,8	19.621.746.901
2011	45,02	141,0	19.827.514.404
2010	45,28	134,1	20.568.719.519
2009	45,88	123,8	20.690.689.830

	Content	Efficiency	tonne - kilometre	Distance
2015	159,8205785	98,44265978	98,81814679	134,3468
2014	169,2376802	97,99177816	92,38875469	133,438044
2013	168,9496809	98,91677914	90,89305135	138,284142
2012	158,578144	99,13481396	94,01321293	129,83695
2011	125,3366986	101,8658387	97,61619361	113,91189
2010	119,5572483	99,72574008	99,13786313	108,288462
2009	100	100	100	100

Source: Own elaboration, with values from EPTMC

These values can be represented in the following figure:

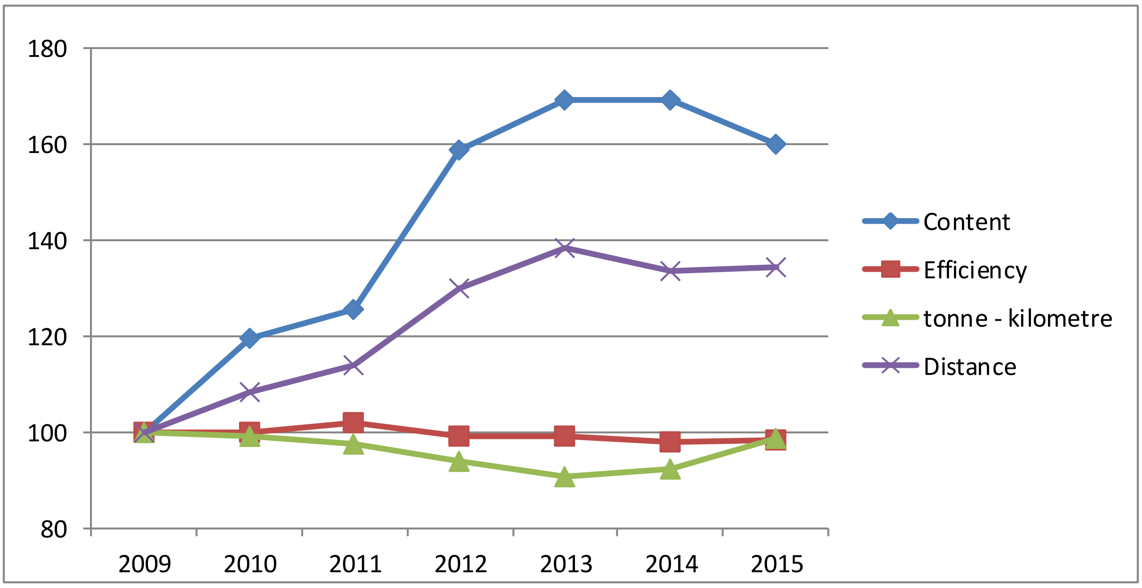


Figure 5.4 – Evolution of indicators in road freight transport in the period 2009 - 2015
Source: Own elaboration, with values from EPTMC

In this second period, the tonnes – kilometre do not experience any increment as they did at the beginning of the century. However, the content and the distance of the goods transported did experience an increase. As said above, the economic crisis of 2008 played an important role in the development of these values.

If we take a look at the relation between the total number of the registered vehicles and the vehicles – kilometre we can observe that both values have been evolving closely. It is true that during the period 2002 – 2007 the evolution of the vehicles registered for the transport of goods raised around 23,5% while the vehicles – kilometre 40,8%, but they both show the similar tendency to increase or decrease.

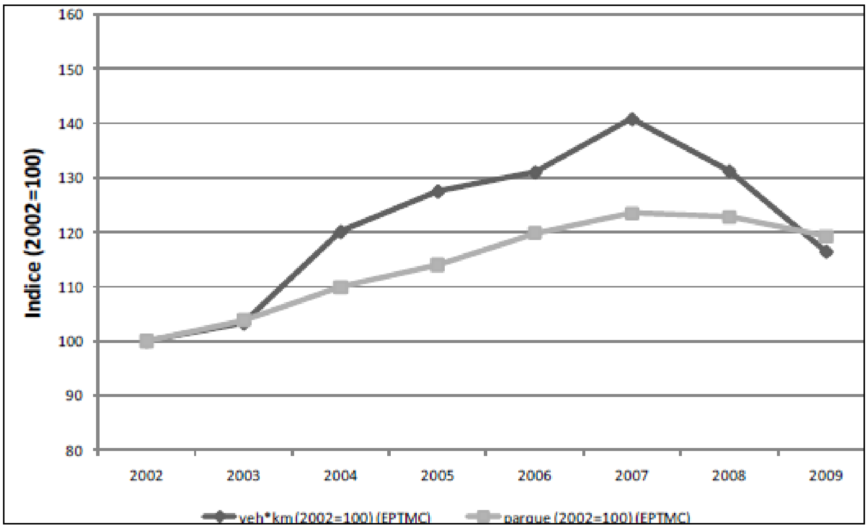


Figure 5.5 – Evolution of vehicles registered and vehicles – kilometre in the period 2002 - 2009
Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España*", 2011

Table 5.3 – Total number of transport vehicles and cargo capacity in the period 2009 - 2015

	Total registered vehicles	Cargo capacity
2015	312.479	5.546.935
2014	302.037	5.202.847
2013	312.742	5.400.991
2012	320.809	5.402.732
2011	349.593	5.997.210
2010	355.324	5.976.745
2009	386.201	6.598.701

Source: Own elaboration, with values from EPTMC

From 2009, the tendency was contrary to the one experienced in the previous years. Here, the vehicles registered decreased in a much higher rate than the vehicles km. from this result, it is fair to think that the transport companies not only use less number of vehicles but they use more the vehicles that they already have, gaining here some benefits for the depreciation costs.

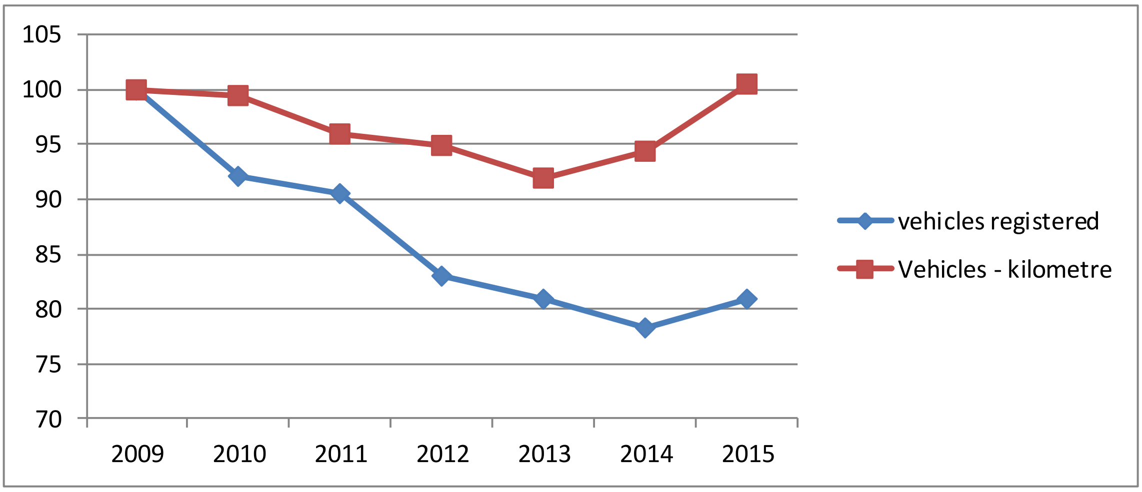


Figure 5.6 – Evolution of vehicles registered and vehicles – kilometre in the period 2009 - 2015
Source: Own elaboration, with values from EPTMC

For the determination of the future situation and the percentage of modal shift from conventional trucks to MegaTrucks it is important to know which kinds of goods are being transported. Not all the goods currently transported in Spanish road would suit properly in a system with MegaTrucks. Thus, it will never be seen a scenario with 100% MegaTrucks on the road.

With the data obtained from EPTMC it is possible to distinguish which are the main types of goods transported (see Annex 3 for the total values):

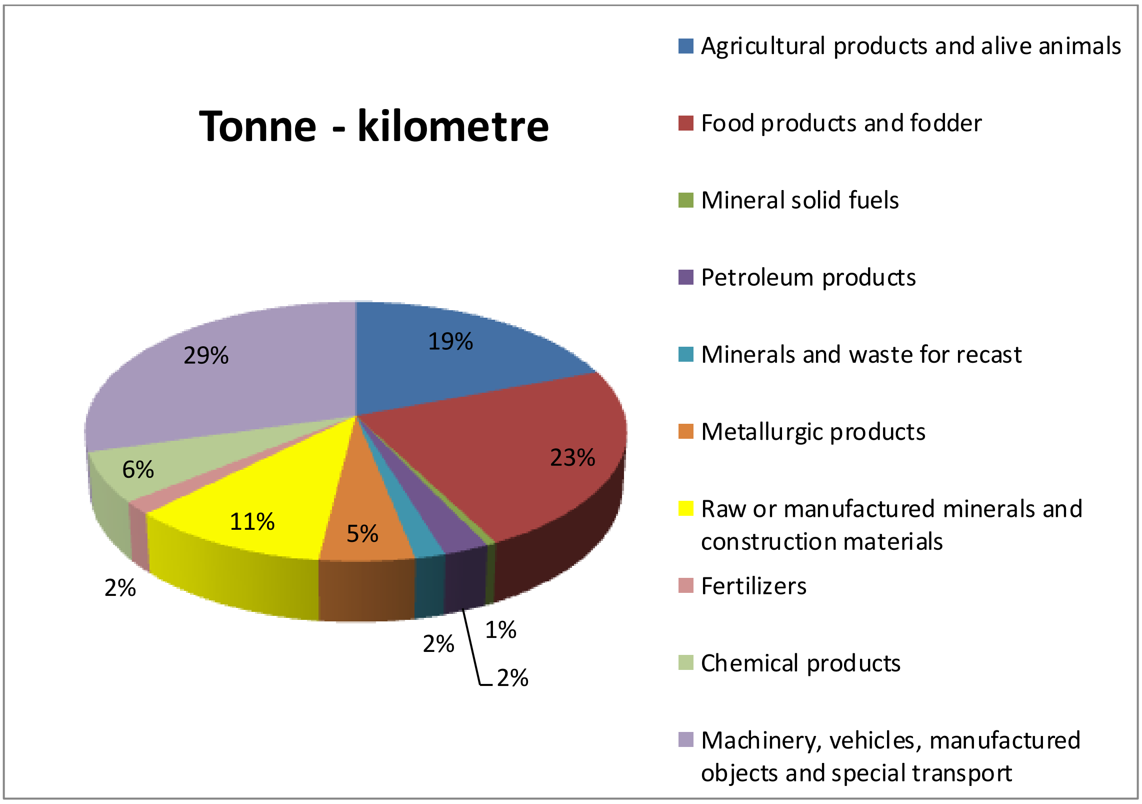


Figure 5.7 – Percentage of the total tonne – km transported per type of good
Source: Own elaboration, with values from EPTMC

Considering the sectorial analysis based on the variable tonne – kilometre for the actual distribution and the regulations stated in the last update from "*Boletín Official del Estado*" in December 2015, one can distinguish which kind of goods could be transported with MegaTruck. Concretely, Agricultural and food products, Machinery and products for the automotive sector, and special transport are the main kind of goods susceptible to be transported with LHV. These sectors account for 71% of the total tonnes – kilometre that are transported with Heavy Goods Vehicles (HGV).

According to A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez in their work "*Efecto de la implementación del MegaTruck de 60 toneladas en España*", in 2011, by analysing values from EPTMC, an estimation of the 72% of the loads are considered to be restricted in terms of weight. In that case, 72% of the previous 71% (of goods susceptible to be transported by MegaTruck) gives a total of 51% of the total tonnes that would be shift to LHV in order to increase their transport productivity. The limitations on volume are not taken into account by two main reasons. First of all, with the values from EPTMC is very hard to determine which type of good is restricted by volume without supposing a lot of parameters. Secondly, while it is true that MegaTrucks will be able to transport around 50% more volume, they will not be able to transport goods of more size than regular trucks of 40 tonnes. That is because in the defined configurations of MegaTruck, the volume that they will be able to transport without dividing the product will be the same.

Of course this value of 51% of the total tonnes transported by HGV is very optimistic. This value does not take into account the time needed for the development of the technology, assuming an instant change of the actual vehicles to LHVs. In the case that the adoption of LHVs would be a real fact, the first years will undoubtedly have a much lower percentage of modal shift. Also, this is only a theoretical number. In reality, not all the companies would change their way of work to adopt this technology.

In the countries where this technology for road freight transport is already a fact, the use of MegaTrucks took around 30% of the total demand of regular trucks of 40 tonnes. What is more, a study conducted by "*The Fraunhofer – Institute for Systems and Innovation Research Karlsruhe*", in May 2012 stated that between 10 – 30 % of the demand for rail freight would experience a modal shift toward Longer and Heavier Vehicles in the case that MegaTrucks would be allowed to circulate in the entire Europe. However, this value has not been verified since that is not a fact yet, so this percentage will not be considered.

The next section of the work includes a cost benefit analysis (CBA) to see if there is a gain or loss in economic terms for the private company as well as for the government. The value of 30% of demand from regular trucks will be used given the fact that is the value empirically obtained from other countries (although one should note that is a very optimistic value).

6. Cost benefit analysis in the three main corridors in Spain

The economic framework for determining the economic and socio – economic impact of many infrastructure projects is the Cost Benefit Analysis (CBA). This tool has been used during years and in many countries is even compulsory when a new project is presented. The CBA consists of comparing two (or more) different scenarios in terms of all costs and benefits involved in monetary terms, throughout the expected life of the policy of the project. The CBA summarizes in just one number the net effect of economic costs and benefits including those which do not have a financial nature, evaluated in monetary units. Obviously, a project is as more useful in an economic (or socio – economic) context as the benefits exceed the costs.

This mentioned number is the Net Present Value (NPV), the sum of the discounted net benefit (or costs) of each year to the present moment. The NPV can be computed as:

$$\boxed{NPV = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+d)^t}}$$

in which:

B_t: benefit at year t
C_t: cost at year t
n: Project lifespan
d: Yearly real discount rate

There can be two different perspectives on a project appraisal:

- Financial viability of a private investment project: a project is viable (profitable) if the effect of the project brings more market share, cash flow or more profit (revenues – costs) to the private company.
- Socio – economic public projects appraisal: A project is viable (useful for society) if it brings more socio – economic benefits than costs. It involves a financial component even the financial costs do not have to be covered by direct financial revenues like taxes or tolls. An example for that are emissions or reduction of travel time. In this appraisal, transfers among economical agents are not considered (for example, tolls are a cost for the user and a benefit for the road authority, so they are not considered in the socio – economic appraisal).

Therefore, in any Cost Benefit Analysis many factors are present; in the specific case for MegaTrucks, a summary of the factors can be seen in the figure below:

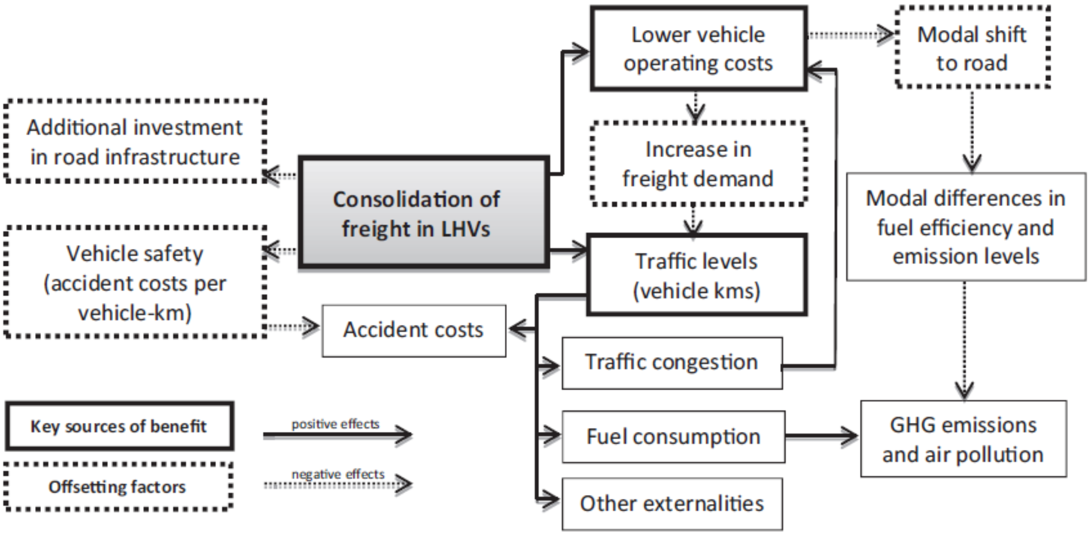


Figure 6.1 – Inter-relationships in the CBA of LHVs
Source: Vasco Sanchez Rodrigues, Maja Piecyk, Robert Mason, Tim Boenders, "*The longer and heavier vehicle debate: A review of empirical evidence from Germany*", 2015

The figure above shows a chart with all the factors that could play a role in the consolidation of freight in Longer and Heavier Vehicles. In this section all the factors will be covered except the induced demand that LHV could create and the modal shift to road. These two mentioned effects are not considered due to high number of hypotheses that have to be made that might not reflect the reality. It is very hard to determine the modal shift without real data without making rough estimation. For this reason it has been decided to omit these factors.

For the comparison, the base scenario will be the actual situation in Spain, where only the use of regular trucks is allowed. This is known as "do – nothing" scenario, while the other scenario, the so called "do – something" scenario attempts to quantify the impact if transport companies were to adopt this new technology for their respective jobs.

For this second scenario, the "do – something" scenario, the full Spanish network will not be considered. According to the regulation PRE/2788/2015, from December 2015 included in BOE and the later update from DGT with the rules that LHV should follow (See Annex 1 and 2), MegaTrucks will only allowed to circulate in specified routes under previous permission. To simplify, MegaTrucks will be able to go from a point A to a point B and vice – versa, from B to A, so the consideration of the full Spanish network in the CBA is not representative since LHV will not be able to travel to third points, C. Thus, only the main Spanish corridors will be considered.

According to the data from EPTMC, the three corridors with greatest number of tonne – kilometre are Barcelona – Madrid, Valencia – Barcelona and Valencia - Madrid. Therefore these three corridors will be studied using a CBA in order to determine if the implementation of MegaTrucks in these routes will produce a positive impact.

Approximate numbers of the tonnes, the distance and the tonnes – kilometres per year are given below:

Table 6.1 - approximation of the number of tonnes, distance and tonnes – kilometres in the three principal corridors in Spain

Tonnes transported x 10^6			
Origin/destination	Barcelona	Madrid	Valencia
Barcelona	-	2,7	2,4
Madrid	2,2	-	2,2
Valencia	3,5	3,7	-

Distance (km)			
Origin/destination	Barcelona	Madrid	Valencia
Barcelona	-	627	382
Madrid	624	-	366
Valencia	383	368	-

Tonne - kilometre x 10^6			
Origin/destination	Barcelona	Madrid	Valencia
Barcelona	-	1.693	917
Madrid	1.373	-	805
Valencia	1.341	1.362	-

Source: Own elaboration, with values from EPTMC

The values between origin and destination in the same city are not 0. Indeed, these values are actually greater than any of the values between two cities, meaning that the transport inside the city is even larger than between cities. However, this option has not been considered since MegaTrucks will not be able to circulate inside the cities.
As said in the previous section, 30% of the total tonnes will be considered susceptible to be transported by MegaTruck. Thus, the tonnes transported matrix results in:

Table 6.2 - approximation of the number of tonnes susceptible to be transported by MegaTruck in the three principal corridors in Spain

Tonnes transported x 10^6			
Origin/destination	Barcelona	Madrid	Valencia
Barcelona	-	0,81	0,72
Madrid	0,66	-	0,66
Valencia	1,05	1,11	-

Source: Own elaboration, with values from EPTMC assuming 30% shift

Once the number of tonnes that will be transported and the distance are defined, it is necessary to study all the costs that are present both in regular truck and in MegaTrucks:

- Amortization: is the sum of the amortization costs of the different elements of the vehicle:

$$A = \frac{C - R - T}{t}$$

In which: A = annual amortization costs
C = acquisition value
R = Residual value
T = Value of the tyres
t = service life

- Financing costs: Sum of the financing costs of the different elements that have been acquired:

$$F = \frac{\left(n \cdot \frac{L \cdot i \cdot j}{j - 1} \right) - L}{t}$$

In which: F = annual financing costs
L = total loan
i = interest
n = financing period
t = service life
j = $(1+i)^n$

- Driver salaries: Costs for the private company of the salaries of the driver.
- Insurance cost of the vehicle.
- Fuel cost:

$$C = \frac{pf \cdot cv \cdot k}{100}$$

In which: C= Fuel costs
pf = price of the fuel (€/l)
cv = consumption of the vehicle (l/100km)
k = kilometres per year

- Maintenance cost of the vehicles

$$M = m \cdot k$$

In which: M = annual maintenance costs

m = kilometric costs of the maintenance of the vehicle
k = kilometres per year

Also, considering the socio – economic impact, it is possible to consider the costs for the government:

- Emissions: using the monetary evaluation for CO_2 it is possible to convert the kg emitted to the atmosphere into money.

  According to some studies from "*Sun Earth*", using the chemical reaction of combustion of diesel we obtain:

$$C_{50}H_{93} + 193/4\ O_2 \longrightarrow 50\ CO_2 + 93/2\ H_2O + \text{Energy}$$

$$1kg\,C_{50}H_{93} \cdot \frac{1mol\ C_{50}H_{93}}{0{,}6943kg\,C_{50}H_{93}} \cdot \frac{50\,mol\,CO_2}{1mol\,C_{50}H_{93}} \cdot \frac{0{,}044\,kg\,CO_2}{1mol\,CO_2} = 3{,}16kg\,CO_2$$

  Thus,

  1 kg Diesel = 3,16 kg CO_2
  1 L Diesel = 2,64 kg CO_2

  According to Irina Prokofieva, Beatriz Lucas, Bo Jellesmark Thorsen and Kirsten Carlsen in "*Monetary values of environmental and social externalities for the purpose of cost-benefit analysis in the EFORWOOD project*", the adopted value for the carbon dioxide emission (considering the upper value) is 0,045 €/kg CO_2. With this relationship it is possible to calculate in monetary terms the social impact regarding emissions of the adoption of LHVs.

- Maintenance cost: the implementation of MegaTrucks will suppose new road infrastructure or, at least, greater defences to prevent fatalities involving these vehicles. This issue will be explained in more detail in section 7.2.2. As explained in that section, the actual maintenance costs of highways can be approximated to 3,39€/km while with the adoption of LHV this value is considered to raise up to 5,08€/km (these values are taken from a study from a country where MegaTrucks are already allowed to circulate).

- Safety costs: Section 8 is a full study of the change in road safety considering the adoption of MegaTrucks. As shown in that section, the impact on the collective road safety can be considered as neutral, so it will not be considered in the cost benefit analysis.

Below, two tables with the costs of regular trucks and MegaTrucks are given:

- Regular truck:

Table 6.3 – Costs and specifications of a regular truck

Maximum weight	40	tonnes
Load capacity	25	tonnes
Number of tyres	12	units
Annual mileage	120.000	kilometres/year
Annual cargo trips	85	%
Annual empty trips	15	%
Fuel consumption	38,5	l/100km
Average price of Diesel	0,934	€/l
Tractor price (420 hp)	130.000	€
Trailer price	40.000	€
Lifetime	8	years
Residual value	20	%
Capital to finance	70	%
Financing time	5	years
interest	2	%
Maintenance costs	0,053	€/km
Insurance costs	7.000	€/year
Average price of a tyre	700	€/unit
Lifetime of a tyre	120.000	km

Source: Own elaboration with values from "*Observatorio de costes del transporte de mercancías por carretera*", January 2016

The values above are taken from Ministerio de Fomento, Gobierno de España, "*Observatorio de costes del transporte de mercancías por carretera*", January 2016. The first three parameters are intrinsic characteristics of regular trucks. The annual mileage of a truck is considered (according to the study mentioned before) to be 120.000 km. Analysing this value, one can see that it results in 600 km per day (supposing 200 work days in a year), a reasonable number for a truck. The fuel consumption and the average price of Diesel are real numbers taken from data registered by regular trucks during the year 2015.

Proceeding in a similar manner, the price of a tractor and its trailer are found in that paper. Also, on average, companies finance around 70% of the capital for buying the vehicle, which has a residual value of 20% of its initial value at the end of its service life (8 years on average). The finance time lasts for 5 years with an actual interest of around 2%. It has to be mentioned that this interest is quite low due to the actual economic situation in Europe, where Euribor accounts for around 0,05% for one year.

The maintenance cost includes reparations and annual revision of the vehicles, while the lifetime of a tyre and its price are given on average. According the study mentioned above, the lifetime of a tyre is slightly higher, around 135.000 km instead of 120.000. However, in order to simplify the problem and considering that this difference does not play a crucial role in the cost analysis, the given value of 120.000 km has been considered to make it the same as the annual mileage.

In a similar way the costs of a MegaTruck have been studied.

- MegaTruck:

Table 6.4 – Costs and specifications of a MegaTruck

Maximum weight	60	tonnes
Load capacity	39	tonnes
Number of tyres	16	units
Annual mileage	120.000	kilometres/year
Annual cargo trips	85	%
Annual empty trips	15	%
Fuel consumption	44,3	l/100km
Average price of Diesel	0,934	€/l
Tractor price (600 hp)	195.000	€
Trailer price	65.000	€
Lifetime	8	years
Residual value	20	%
Capital to finance	70	%
Financing time	7	years
interest	2	%
Maintenance costs	0,065	€/km
Insurance costs	10.000	€/year
Average price of a tyre	700	€/unit
Lifetime of a tyre	120.000	km

Source: Own elaboration with values from "*Observatorio de costes del transporte de mercancías por carretera*", January 2016 and "*LHV in practice*"

The determination of the costs for a MegaTruck is rougher since they are not implemented in Spain yet. The values for the load capacity are determined as intrinsic characteristics, while the number of tyres corresponds to configuration D. according to the companies that develop MegaTrucks the life time of one vehicle is expected to be the same and the fuel consumption is around 15% more than a regular truck due to higher power of the tractor. This value has been taken from "*LHV in practice*" form The Netherlands, where LHVs are already operating. The residual value is expected to be the same while the financing time is higher (7 years) due to the higher investment and loan. The maintenance costs are 20% higher in these trucks because they should pass through more inspections. The insurance costs are also higher taking into account all the risks that LHV have (nevertheless, the value of the insurance costs for a MegaTruck is guessed since the insurance costs in The Netherlands might not correspond to Spain).

Thus, according to the values exposed before (see the full calculation in Annex 4):

Annual amortization and financing costs of a regular truck (per unit):

$$A = 15.950{,}00€$$
$$F = 923{,}52€$$

Annual amortization and financing costs of a MegaTruck (per unit):

$$A = 24.600{,}00€$$
$$F = 1.895{,}57€$$

The costs exposed before correspond to the financial costs of the vehicles. On the table below a summary of the operational costs can be found. The operational costs are the sum of the maintenance costs and personal costs related to the activity of the truck. Maintenance costs can be understood as tyres, oil, breaks, etc., while personal costs are the salaries of the drivers.

Table 6.5 – Operational costs for regular trucks

Regular truck

Annual Salary driver	30.000 €	
Salary cost per km	0,250	€/km
Maintenance costs	0,053	€/km
Tyre cost	0,070	€/km
Insurance cost	0,058	€/km
Fuel cost	0,360	€/km
TOTAL OPERATIONAL COSTS	0,79 €	€/km

Source: Own elaboration

Table 6.6 – Operational costs for MegaTrucks

Mega truck

Annual Salary driver	40.000 €	
Salary cost per km	0,333	€/km
Maintenance costs	0,065	€/km
Tyre cost	0,093	€/km
Insurance cost	0,083	€/km
Fuel cost	0,414	€/km
TOTAL OPERATIONAL COSTS	0,99 €	€/km

Source: Own elaboration

According to statistics, the average salary for truck drivers in Spain is 30.000€. Since the last regulation in Spain states that MegaTruck drivers should have at least several driving experience, the salary has been considered to be 40.000€. The other values have been found by dividing the total costs in table 6C by the annual mileage, 120.000 km. The maintenance costs (that were already given per kilometre) are taken from Ministerio de Fomento, Gobierno de España, "*Observatorio de costes del transporte de mercancías por carretera*", January 2016, with an increase of 20%.

However, these tables have some limitations. There are some operational costs that are 100% variable, such as the tyre costs or the fuel. These costs fully depend on the kilometres that the vehicle will drive, while other costs like the salary of the driver or the insurance will be paid regardless of the mileage.

The costs depending on the trip (number of kilometres) are resumed in the following calculation:

Table 6.7 - Cost - Benefit Analysis for the private company and socio – economic impact for the government in the corridor Barcelona – Madrid

Barcelona - Madrid		
Annual demand	810.000	tonnes
Distance	627	kilometres

REGULAR TRUCK			MEGATRUCK		
Number of required operations	32.400		Number of required operations	20.769	
TOTAL NUMBER OF KILOMETERS	20.314.800		TOTAL NUMBER OF KILOMETERS	13.022.308	
Number of trucks	199,16		Number of trucks	127,67	
NUMBER OF REGULAR TRUCKS	200		NUMBER OF MEGATRUCKS	128	
Amortization costs	3.190.000 €		Amortization costs	3.148.800 €	€
Financing costs	184.704 €		Financing costs	242.659 €	€
Operational costs	16.067.449 €		Operational costs	12.872.922 €	€
Total	19.442.153 €		Total	16.264.381 €	
discount rate	5,50	%	discount rate	5,50	%
Lifetime of each truck	8,00	years	Lifetime of each MegaTruck	8,00	years
NPV	123.157.604 €		NPV	103.027.794 €	
			% of Savings	16,34%	

Socio - economical analysis

REGULAR TRUCK			MEGATRUCK		
Monetary value for emissions	0,045	€/kg CO_2			
Maintenance costs	2.125,53	€	Maintenance costs	3.185,16	€
Emissions	241,40	l	Emissions	277,60	l
	637,28	€/kg CO_2		732,88	€/kg CO_2
Total emissions	127.456,56	€/kg CO_2	Total emissions	93.808,03	€/kg CO_2
	5.735,55 €			4.221,36 €	
NPV maintenance costs	13.464,31 €		NPV maintenance costs	20.176,61 €	
NPV emission costs	36.332,19 €		NPV emission costs	26.740,49 €	

ΔMaintenance costs	6.712,30€
ΔEmissions	-9.591,70€
B/C*	-1,4289742

*Ratio Benefit over costs (ΔEmissions / ΔMaintenance costs)

Source: Own elaboration

Table 6G shows the difference on costs between using regular trucks or MegaTrucks in the route Barcelona – Madrid. As it is possible to observe, by using regular trucks a total number of 200 vehicles is needed. For the determination of this number, the total amount of tonnes that have to be carried have been divided by the load capacity of a regular truck. With this, the number of operations is found, a value that can be converted to operations x kilometre or, what is the same, total number of kilometres. To determine the number of vehicles, the total number of kilometres has been divided by the annual mileage (loaded, 85% according to table 6C) of each truck, obtaining a result of 200 regular trucks. The same procedure has been followed for MegaTrucks, obtaining a value of 128.

Some considerations have been made, for example, that MegaTrucks will have the same distribution of cargo and empty trips (85% - 15%). This assumption might not be true since, according to the last regulation, LHVs will be more restricted to the routes they follow. However, this issue will be studied later. In order to get a first idea about the total costs this distribution has been considered the same.

At the end, by comparing the Net Present Value of the costs, it is possible to observe that with these assumptions the scenario with MegaTrucks will have 16,34% reduction of costs.

Also, when comparing the socio - economic analysis, the ratio B/C appears to be favourable for the government, where B/C is larger than one (B>C). There are many other social effects that have not been considered. For example, the nuisance, the probability of congestion of the perceived safety for the drivers are not considered since the monetary value of these costs differs highly regarding the organisation that performs the study. However, the impact on collective road safety is supposed to be neutral as it is supported in section 8.

If we now take a look to the corridor Barcelona – Valencia some other conclusions can be made. The first and obvious difference is that the distance is lower in that corridor. Also, the total annual demand of tonnes to be transported is significantly lower in that case.

Table 6.8 - Cost - Benefit Analysis for the private company and socio – economic impact for the government in the corridor Barcelona – Valencia

Barcelona - Valencia		
Annual demand	720.000	tonnes
Distance	382	kilometres

REGULAR TRUCK

Number of required operations	28.800
TOTAL NUMBER OF KILOMETERS	11.001.600
Number of trucks	107,86
NUMBER OF REGULAR TRUCKS	108

Amortization costs	3.190.000 €
Financing costs	184.704 €
Operational costs	8.701.422 €
Total	12.076.126 €

discount rate	5,50	%
Lifetime of each truck	8,00	years
NPV	76.497.018 €	

MEGATRUCK

Number of required operations	18.462
TOTAL NUMBER OF KILOMETERS	7.052.308
Number of trucks	69,14
NUMBER OF MEGATRUCKS	70

Amortization costs	1.722.000 €	€
Financing costs	132.704 €	€
Operational costs	6.971.407 €	€
Total	8.826.111 €	

discount rate	5,50	%
Lifetime of each MegaTruck	8,00	years
NPV	55.909.583 €	
% of Savings	26,91%	

Socio - economical analysis

REGULAR TRUCK

Monetary value for emissions 0,045 €/kg CO_2

Maintenance costs	1.294,98	€
Emissions	147,07	l
	388,26	€/kg CO_2
Total emissions	41.932,60	€/kg CO_2
	1.886,97 €	

NPV maintenance costs	8.203,14 €
NPV emission costs	11.953,12 €

MEGATRUCK

Maintenance costs	1.940,56	€
Emissions	169,13	l
	446,50	€/kg CO_2
Total emissions	31.255,32	€/kg CO_2
	1.406,49 €	

NPV maintenance costs	12.292,61 €
NPV emission costs	8.909,50 €

ΔMaintenance costs	4.089,47 €
ΔEmissions	-3.043,62 €
B/C	-0,7442574

Source: Own elaboration

In this case the percentage of savings for the private companies is still positive regarding the costs involved in the transport of the tonnes. However, in that scenario the government has a negative effect on the road, since the ratio B/C is below one. Here, the costs involved in the maintenance / improvement of the highways in order to allow MegaTrucks circulate is higher that the social benefit of the reduction of emissions.

It has to be said that this costs for society can vary a lot regarding other type of emissions and or, the real maintenance costs that might appear if LHVs would be circulating (the value of the maintenance costs is explained in section 7.2.2 but is still quite uncertain).

In Annex 4 it is possible to see all the calculations for the other corridor, Valencia – Madrid. In this case, there is a reduction for the private companies of 19,73% and also a benefit for the government:

Table 6.9 – Results of the Cost - Benefit Analysis for the private company and socio – economic impact for the government in the corridor Valencia - Madrid

For private investors:

NPV (trucks)	**103.239.227 €**

NPV (MegaTrucks)	**82.873.605 €**
% of Savings	**19,73%**

For the government:

ΔMaintenance costs	3.939,59 €
ΔEmissions	-4.536,71 €
B/C	-1,15156917

Source: Own elaboration

Considering now another distribution for the empty trips for MegaTrucks the results can vary in a significant way. If a distribution for the cargo trips and the empty operations of 60% - 40% respectively is considered (keeping the 85% - 15% for regular trucks), the percentage benefit for private companies will be only 9,12% in the corridor Barcelona - Madrid. Also, for the government this option is even worse, where the total number of emissions will be even higher than the option with regular trucks (B/C<0) what means, of course, that the ratio B/C is much worse. The maintenance costs for the government are not increased because it does only depend on the kilometres between Barcelona and Madrid.

One of the biggest problems for the implementation of MegaTrucks is the way that they are allowed to circulate. The last regulation states that they are only allowed to circulate from A to B, without the option to deviate or to make other types of operations. That is actually the main problem for private companies that have to transport goods from one point to another one, but not the in the other direction. For instance, companies such as supermarket chains or distribution fashion textile need to transport a large amount of products from their factories to the final shops or logistic centre. However, it is very hard for these companies to find a way to fill the MegaTruck and make the reverse trip, from B to A. In that case, MegaTrucks will only perform 50% of the trips with cargo while the other 50% will be empty operations. In there will be still a benefit for the private company, but only accounting 4% (considering Barcelona – Madrid) (see Annex 4 for the calculation).

Table 6.10 – Results of the Cost - Benefit Analysis for the private company and socio – economic impact for the government in the corridor Barcelona – Madrid in the case with 50% cargo trips

For private investors:

NPV (trucks)	**123.157.604 €**	**NPV (MegaTrucks)**	**118.133.322 €**
		% of Savings	**4,08%**

For the government:

ΔMaintenance costs	6.712,30€
ΔEmissions	9.210,21€
B/C	1,37214

Source: Own elaboration

At this point, it is licit to think that private investors are not that interested at buying MegaTrucks since the benefits are not that high. The actual regulation is very strict in order to make this idea progress and catch the interest of the majority of companies.

Though, is has been showed that if this new technology reaches a high number of cargo operations the benefits of using MegaTrucks clearly overcome the costs, with a notable reduction of operational costs and also of social costs. Logistic operators should focus on getting the maximum profit on it and avoid unnecessary empty trips.

7. Traffic Safety

7.1 Introduction

In many countries, one of the main conditions for the adoption of Larger and Heavier Vehicles for the freight transport system is that traffic safety must not be affected in a negative way. For the study of safety two different approaches can be used: safety can be measured objectively, with facts, figures and statistics, or it can be measured in a more subjective view, taking into account the experience of users. This type of safety is of importance when a new type of vehicle, such as a MegaTruck is introduced. It can be tracked by studying and analysing the experiences and perceptions of road users sharing the public space with a LHV.

Safety has been playing an important role in the las decade. European directives are more and more becoming stricter with regulations in order to prevent fatalities and avoid social costs. The figure below shows how the different implementations that governments applied over the years helped considerably on the road safety, concretely on the number of fatalities (particular case for The Netherlands, but similar in every European country).

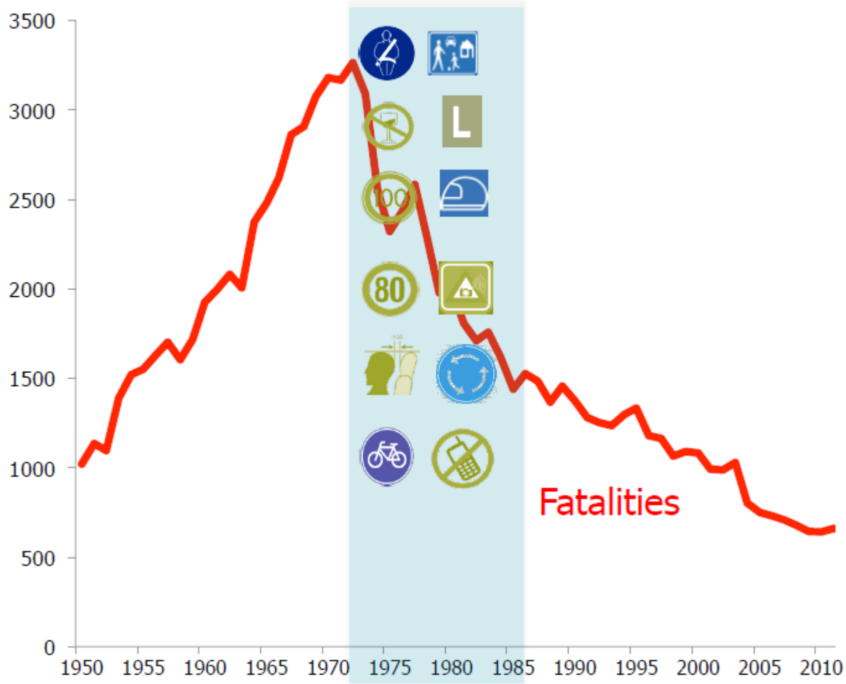


Figure 7.1 – Number of fatalities through the years
Source: Inaugural speech Hagenzieker, 2015

However, not only fatalities should be taken into account. Unfortunately, the number of seriously injured people related to traffic accidents remains high. This high value of severe injured people involved in road accidents make us reflect and think about the proper ways to introduce new technologies on the road without increasing, or even reducing the risk level of the road.

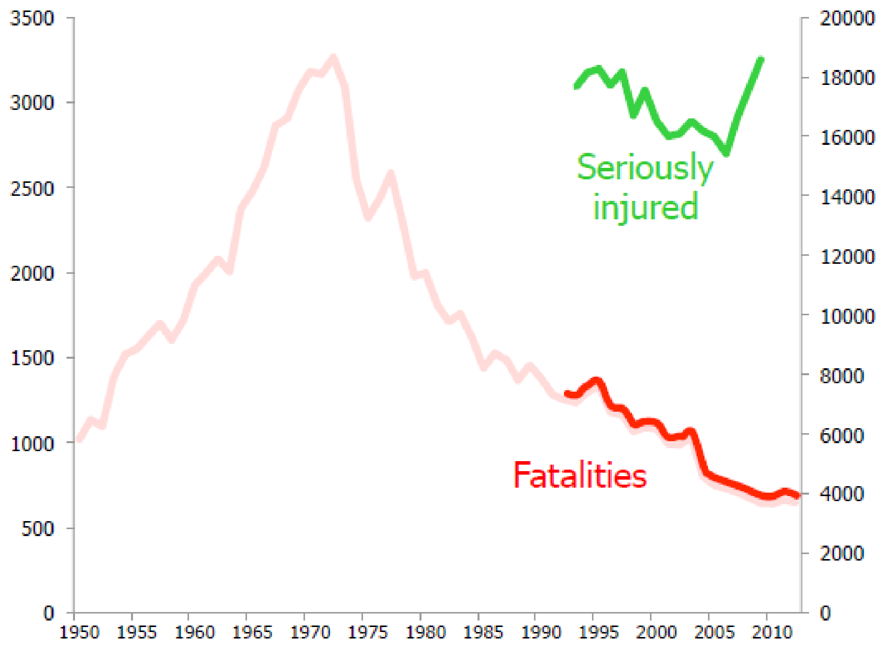


Figure 7.2 – Number of fatalities through the year and number of fatalities
Source: Inaugural speech Hagenzieker, 2015

As said above, there are several ways to evaluate road (un)safety. The absolute number of road crashes, their seriousness in terms of fatalities and injury severity or relative measures such as the number of crashes per distance travelled (named exposure) or the number of fatalities per 100.000 inhabitants (mortality rate) are clearly objective factors.

On the other hand, safety performance indicators and perceived safety are clearly subjective. One can understand safety performance indicators as the link between road safety measures and casualties. For instance, the use of the seat belt, the % of alcohol offenders, lights, speed phones and many other parameters can be defined as safety indicators. Also, there are other influencing factors such as traffic volume on the road, the distribution of this traffic, the road design characteristics and road safety measures, factors directly related to the adoption of the use of Larger and Heavier Vehicles.

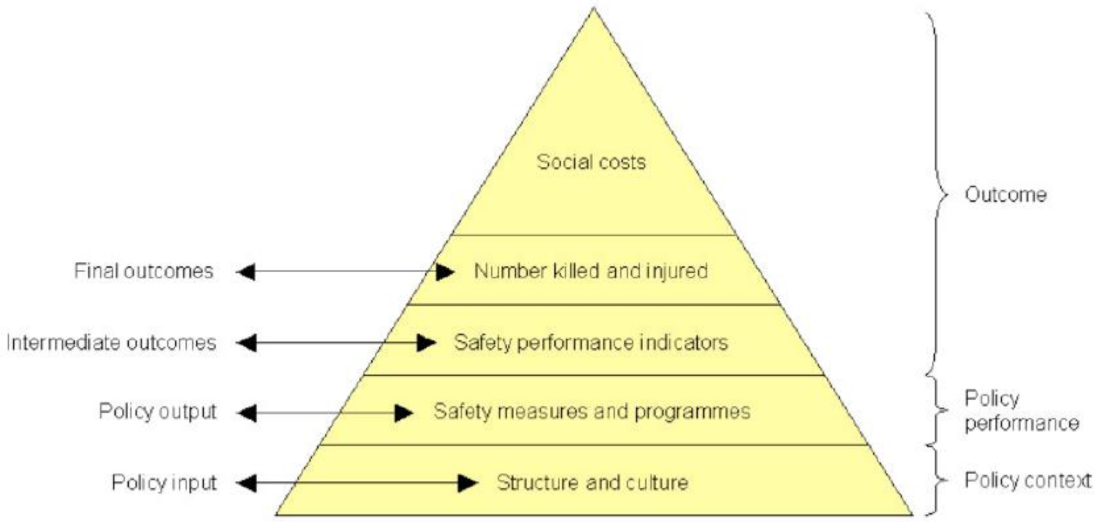


Figure 7.3 – Safety pyramid: characteristics of road safety
Source: Wegman, "*Towards a composite road safety performance index*", 2008

Because of all these factors, road safety cannot be omitted when the implementation of a new technology is being studied. In this part, an overview on road safety with the implementation of MegaTrucks will be studied. Since the implementation in Spain is not a real fact yet, it is hard to determine the objective safety in Spanish roads with real statistic and figures. Thus, the next section is a review from an exhaustive study from a country where the use of a LHV is already a real issue. In that study, the safety with these vehicles on their roads in objective and subjective terms has been studied.

Later, a review of the different parameters and road characteristics that MegaTrucks need will be described. To finish this section, a Macro – simulation software has been used to simulate how would be the situation in Spain if LHVs would be fully in operation. With the simulation it is possible to obtain some objective parameters such as the speed profile, the headway between vehicles or the number of lane changes carried out by normal cars, conventional trucks o MegaTrucks. By comparing the plots obtained from different scenarios it will be possible to indicate an estimation of the traffic safety if the implementation of these vehicles would be a real fact in Spain.

7.2 Review of objective and subjective perception in countries with already using LHV.

7.2.1 Previous studies analysing objective safety:

Objective safety is the safety related to objective indicators such as the number of total accidents or several injuries. In order to do so, it is necessary that LHV are already operating on the roads. As said in section 2.2.4 The Netherlands is one of the countries where the circulation of MegaTrucks is permitted. This allowed the country to perform several studies after some time of its implementation.

In the study "*increase maximum vehicle length for vehicles in domestic transport*" (Original: *Verhoging maximale voertuiglengte voor combinatievoertuigen in het binnenlands vervoer*), published by NEA, it is concluded that for an LHV the risk characteristics are similar to those of a conventional truck. This is true as long as the MegaTrucks meet a sum of preconditions such as a better braking system able to stop the vehicle with higher mass, vehicle stability or driver's field of vision.

According to the group that performed the project, objective traffic safety is largely determined by the number of kilometres that MegaTrucks will be driving through. For instance, in a hypothetic scenario with all MegaTrucks instead of conventional trucks the total number of heavy vehicles on the road would decrease by 33%, a fact that has a very positive effect on traffic safety. On the other hand, intrinsic characteristics from MegaTrucks could increase the risk of an accident where one of these vehicles is involved in, with a major probability of severe injury. Additionally, the skills of the driver are considered of importance as well in term of reducing the risk involving MegaTrucks.

The ministry of transport, public works and water management, "*Rijkswaterstraat*", studied in 2010 the factors and safety related to LHV from the period of their trials. Objective traffic safety was studied in several different ways. In addition of the total number of accidents and injuries, the researchers made some interviews to other road users and observed driver behaviour. Due to the limited scope of MegaTrucks it was easy for the researchers to identify the accidents involving these vehicles. No major accidents occurred during the trial time, mainly because of the small number of LHV (around 400) and also, according to "*Rijkswaterstraat",* due to the fact that LHV drivers were the best conventional truck drivers among professional drivers. They had more responsibility and more experience. However, this fact could change if some day MegaTrucks are becoming more common and less experienced drivers will have to drive these vehicles.

When observing the driving behaviour of LHV drivers, it did not show any negative impact on the traffic safety to the researchers. Since the circulation for LHV was restricted to specific routes, drivers were usually aware of possible problems on the road. The researchers that conduct this study interviewed as well the drivers of MegaTrucks. Below, some technical aspects that the drivers reported are listed:

- *"Sharp turns: When making a sharp right turn, LHV-drivers sometimes need to use two lanes in order to properly make the turn;*

- *Intersections: During interviews some LHV-drivers indicated that sorting lanes at certain intersections are sometimes too short. Drivers sometimes also need to move over hatched road markings, but this situation does not differ from driving a regular truck combination. It is an issue that needs attention, because LHVs (and regular trucks) can quickly fill a sorting lane and thus block the main road. This may have a negative effect on traffic flow and traffic safety;*

- *Acceleration: LHV-drivers feel that it takes longer to gain speed in an LHV, even though tests have shown that the acceleration speed of an LHV is not lower than of a regular truck. The green light window of some traffic lights is too tight and short lanes make merging difficult*

- *Parking: At this moment there are not enough LHV-parking spaces. In addition to that, drivers are calling for the installation of special LHV-coupling sites in core areas in order to make maximum use of the flexibility of the LHV-concept;*

- *Manoeuvring space: Driving in reverse with an LHV is more problematic than with regular trucks. This is especially problematic around distribution centres where space is sometimes limited. The installation of dedicated loading/unloading docks is very much welcomed by LHV-drivers;*

- *Road work: In the event of road work there currently is insufficient consideration for LHVs in terms of detours and road blocks;*

- *Breakdown areas: Some breakdown areas are too short for LHVs."*

- *Vehicles are not recognizable enough from the sides, so during overtaking or merging, other road users may find out too late that they are dealing with a vehicle that is extra-long. Especially in situations with short merging lanes, and on busy motorways with a high density of entries and exits this may be risky;*

Source: Rijkswaterstraat, "*Longer and Heavier vehicles in The Netherlands"*, March 2010

Some years earlier, in 2008, *"CROW"*, the technology platform for transport, infrastructure and public space in Holland, conducted a research with the aim of investigating the accident risk of a MegaTruck in comparison of a conventional truck. In this study, "*CROW"* was focusing on the individual risk of a LHV vehicle and not on the collective risk and general traffic safety of the road like the other studies exposed above.

Together with the institute of Traffic Safety Research ("*SWOV"*), "*CROW"* gave answers related to three possible situations. The individual risk of a MegaTruck was studied regarding: 1) the interaction with vulnerable road users (such as cyclists or moped riders), 2) the possible effect on two-wheelers being sucked in by LHV and 3) the risk during twilight or darkness.

For the first situation, the interaction of an LHV with vulnerable users was problematic especially at intersections. "*SVOW*" observed that before turning to the right, an LHV is likely to move to the left in order to make the turn properly. At that moment, mopeds and vulnerable users are not expecting therefore that the MegaTruck will move in their direction, leading to a dangerous situation for the weaker user. The conclusion of this situation was the following: In situations where vulnerable users are not positioned immediately next to a MegaTruck, this problem does not occur. In the case that the vulnerable users are directly to the right of a MegaTruck, they are not in more danger that next to a conventional truck. However, according to last update of the Spanish legislation, these situations are not likely to occur in Spain since MegaTrucks are restricted to circulate on predefined routes where mopeds and vulnerable users are not allowed to enter or have a separate infrastructure to ride.

A passing vehicle displaces air, a fact that might create a negative effect on motorbikes on highways. "*SVOW*" performed some test to study the effect of this negative pressure on motorbikes created by LHV, and concluded that the effect are no different than a regular truck. The conclusion of this situation is that motorbikes do not have additional danger when overtaking a LHV instead of a regular truck in highways in terms of negative pressure.

The last situation that "*CROW"* and "*SWOV"* studied for the individual risk of a MegaTruck is the risk they have during twilight or darkness. Regarding the rear end collisions, an LHV has the same risk than other truck combinations. The presence of side markings does not make any difference between regular trucks and MegaTrucks in reducing the risk of read end conflicts. Nevertheless, the risk of a side collision does seem greater when talking about LHVs. Overtaking a MegaTruck is more risky when the driver does not notice that he / she is dealing with it. Therefore, the mandatory appropriate sign on the back of the vehicle must be clearly visible at night. Indeed, after some surveys to LHV's drivers, the answers were that they think that their vehicles are not recognizable enough from the back and the sides, so the other road users might find out too late that they are dealing with a MegaTruck.

Apart of the 3 situations that "CROW" studied where a MegaTruck can have more individual risk that regular truck there are other individual risk factors for LHVs. For instance, the field of view was one issue highly debated in the rejection from UK of MegaTrucks. Using CAD models, 3 main conclusions appeared:

- While traveling straight ahead or when changing lanes, MegaTrucks' field of view would be similar than regular trucks.
- When turning, LHV would suffer more blind spots than regular trucks. The associated risk, therefore, will be higher for LHV.
- Configuration D (see section 2.1) would have the minimal impact on the visible ground plane area compared with conventional trucks.
-

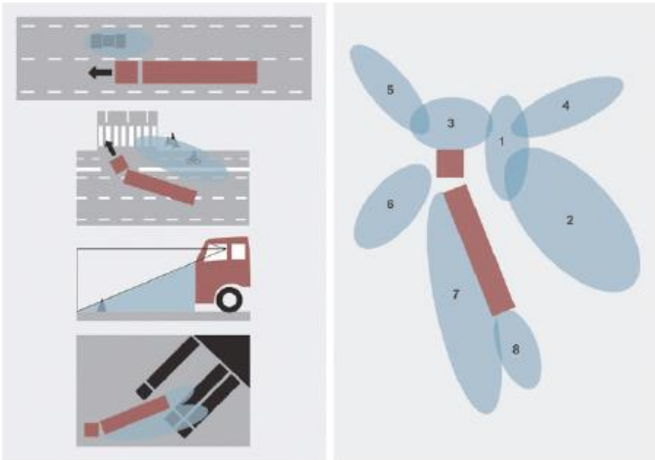


Figure 7.4 – Blind spots for a regular truck seen form above
Source: Volvo Trucks

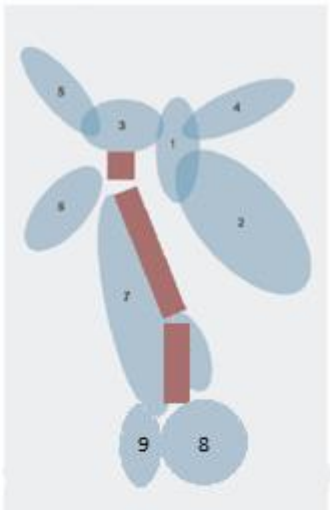


Figure 7.5 – Blind spots for a MegaTruck seen form above
Source: Own elaboration

To cope with these blind spots, new technologies would be necessary such as the implementation of cameras. However, the workload of the driver has to be considered to avoid overloading.

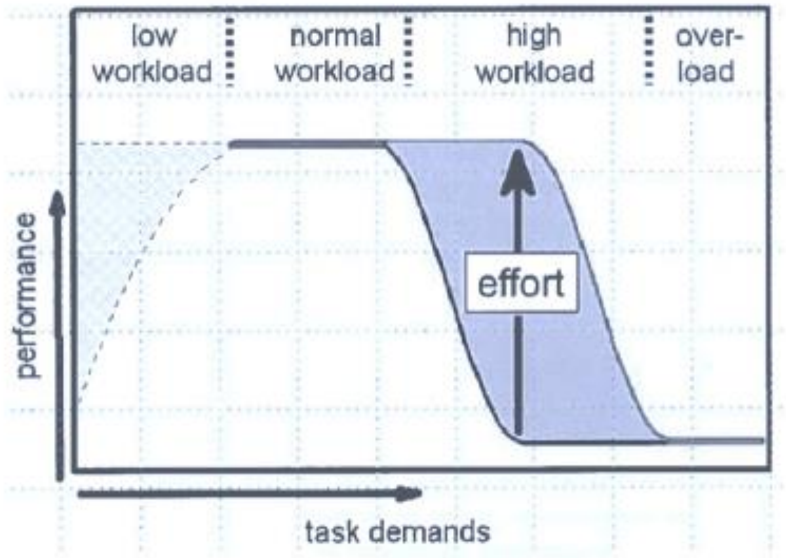


Figure 7.6 – Task demand – performance relationship
Source: Veltman and Jansen, 2003

When the task demands are too low there is underload. This might lead the driver to distraction or boredom. Then there is high workload, by investing more effort one can keep performance at an adequate level. When the task demands approach the maximum resources available one speaks of overload, a situation that may end up in a dangerous situation for the driver and for the rest of the users.

7.2.2 Safety factors for MegaTrucks: impact on infrastructure

As exposed before in section 5 (The freight transport system in Spain), the total number of heavy vehicles registered in 2015 was 312.479. This number represented 1,01% of the total vehicles registered in Spain in the same year (30.976.047 vehicles, according to "*Ministerio de Fomento, Series parque de vehículos*"). That year a total number of 91.570 accidents occurred, and 4.018 of them were involving a heavy vehicle, representing 4,39% of the total number of accidents. This value gives us an idea that the heavy vehicles have a higher accident rate with regard to the global vehicles in the country.

It is also possible to look at these values from another perspective. If we take a look at the statistics per vehicle (number of accident per vehicle), globally, 0,29% of the vehicles in Spain were involved in an accident with fatalities (91.570 accidents with

30.976.047 vehicles). We can see this number as 29 accidents for each 10.000 vehicles. In the case of HGV this number increases up to 1,29%, so 129 accidents per 10.000 heavy good vehicles (4.018 accidents out of 312.479 HGVs) this number represents 4,13 times more than the total number of vehicles.

In the following table it is possible to observe these values:

Table 7.1 – Accidents overview in Spain

	Total number of registrations	Accidents	Ratio
HGV	312479	4018	1,29%
Total vehicles	30976047	91570	0,296%
Ratio	1,01%	4,39%	

Source: Own elaboration with values from EPTMC and Ministerio de Fomento

It is true that the values given above were in terms of absolute numbers. When talking in relative terms, the accident rate of HGV is lower than the rest of the vehicles due to the fact that regular trucks, on average, travel 5 times more than the rest. However, the high absolute percentage of the accident rate obliges us to focus on road safety, especially when the introduction of a new technology is being the focus of the study.

To start with, a review of the different impacts that a LHV can have on the road infrastructure is given.

- **<u>Pavement</u>**

Multiple studies have been performed for the wear of the pavement. The results of these studies differ depending on the position of the company who realized it. For instance, some companies in favour of the adoption of LHV state that the wear will be higher but affordable for the government in comparison of the benefits it has. Also, the weight is increased but also the number of axles, so the weight per axle does not increase that much. On the other hand, companies against the implementation of the MegaTruck state that the current infrastructure is not ready to support these loads on it.

In this report, the revision of the wear of the pavement is not studied because of a lack of means to do so. Further investigation is needed in order to see if the pavement really needs extra maintenance.

- **Structures (bridges)**

The study of the structures in Spain road network needs high focus due to the large and severe consequences that a collapse of a bridge would imply. In that study two main aspects are distinguished: fatigue and maximum load. The impact on the structures was studied by A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez in their work "*Efecto de la implementación del MegaTruck de 60 toneladas en España*", in 2011, and also in the work by Oficemen "*Estudio sobre la viabilidad de la mejora en el transporte de mercancías mediante el uso de MegaTrucks*". These two different projects differ significantly in their results. The results exposed in this section are referred to these projects.

The fatigue resistance of a structure is hard to know due to the need of the exact material and dimensions of each structure. For this reason, fatigue resistance is obtained with an approximation of the maximum load a bridge can handle. The two main aspects of the maximum load are the maximum shear strength and the bending moment. To state if a bridge can handle a determined load it is important to refer to the current normative: IAP-11 "*Instrucción sobre las acciones a considerer en el Proyecto de puentes de carretera*" from 2011.

According to this norm, A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez developed a model with the worse situation for the shear strength and the bending moment, and concluded with some increment of strain in the bridge depending on the configurations.

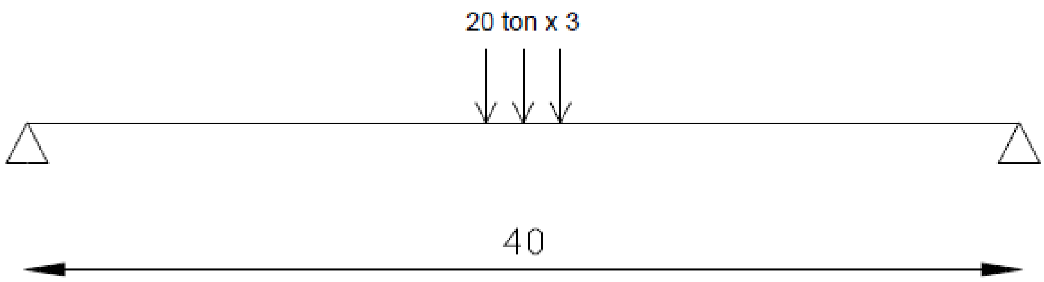


Figure 7.7 – Overview of the worse distribution for bending moment in a 40 metre span bridge
Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España",* 2011

With this configuration, considering that the bridge has a width larger than 12 metres (it is then necessary to have two cargo vehicles at the same time in parellel), the maximum bending moment at the center of the span is:

$$M = 1170\ mt$$

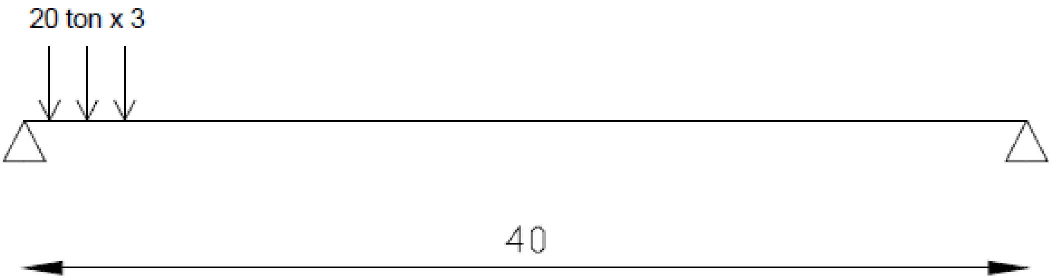


Figure 7.8 – Overview of the worse distribution for shear strength in a 40 metre span bridge
Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España",* 2011

Following the procedure above, the maximum shear stress in that situation is:

$$V = 107{,}7\ ton$$

According to Oficemen in "*Estudio sobre la viabilidad de la mejora en el transporte de mercancías mediante el uso de MegaTrucks*", considering now the worst case, a bridge loaded with MegaTrucks in its entire span, (a full MegaTruck at the worse position and two more MegaTrucks with only some of their axles in the front and back position due to its length) the configuration of the loads is now the following:

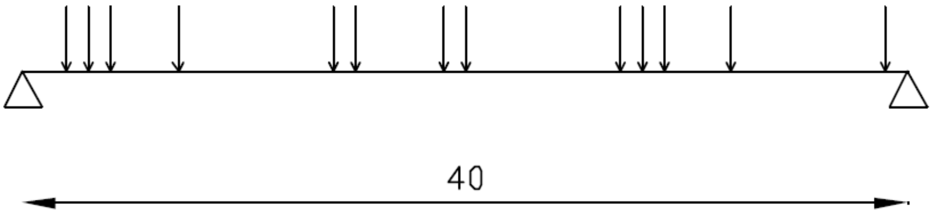


Figure 7.9 – Overview of the worse situation in a bridge fully loaded
Source: Officeman, "*Estudio sobre la viabilidad del MegaTruck*"

Where all the loads now have a value of 15 tonnes.

With this configuration of loads the maximum bending moment and shear strength is now:

$$M = 967{,}5\ mt$$
$$V = 105{,}7\ ton$$

If we compare the results obtained in this worst situation and the scenarios above, it seems that the MegaTrucks do not suppose any excess of load with regard to the maximum load that a bridge can handle. Only in those bridges that were built earlier than the current norm IAP-11 must be checked.

However, the results from A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez in their work “*Efecto de la implementación del MegaTruck de 60 toneladas en España*”, in 2011 differ from these results. In that study the authors concluded that an additional strain does occur:

Table 7.2 – Estimation of the increment of costs in structures

MegaTruck configuration	Additional Strain (%)	Total cost (€/km)	Additional Cost (€/km)
Actual	0	4.220	0
A	42,478	6.012	1.792
B	42,37	6.008	1.788
D	42,075	5.995	1.775

Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, “*Efecto de la implementación del MegaTruck de 60 toneladas en España”,* 2011

As said above, it is hard to determine the exact value of cost increment since the reality might differ from the model. Further research is needed in this issue in order to end with a final and clear result.

- **<u>Geometry of the roads</u>**

According to Carlos Kraemer in his book “*Ingeniería de Carreteras*”, in 2004, the minimum turning radius of a regular truck is exposed in figure 7J.

According to Oficemen, In a general way, it is possible to conclude that a minimum radium for a vehicle of 25,25 meters should be at least of 15 meters. Preferably, to avoid problems with the geometry of the road, the radius should not be less than 18 meters in exits and 20 meters in roundabouts (20 and 22 meters preferably).

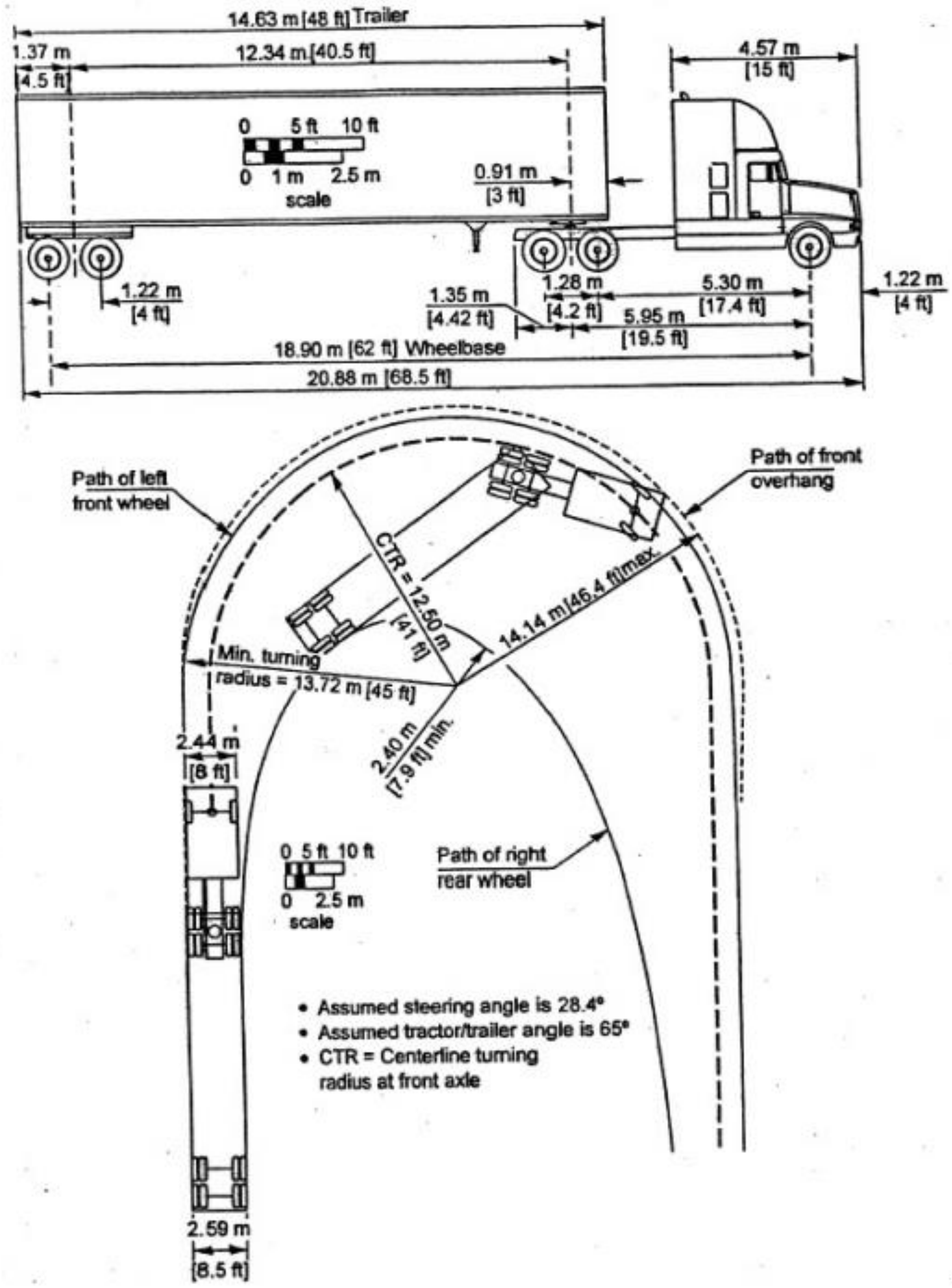


Figure 7.10 – Geometrical analysis of the turning radium of a regular truck with known dimensions
Source: Carlos Kraemer, "*Ingeniería de carreteras*"

- **<u>Tunnels</u>**

Regarding the safety in tunnels, the main problem appears with regard to accidents. No further studies will be performed in this project, the results are taken from A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez in their work "*Efecto de la implementación del*

MegaTruck de 60 toneladas en España". The safety measures regarding safety in tunnels are divided in 4 sections:

1. Basis for deciding the safety measures
2. Measures in infrastructures
3. Measures related to exploitation
4. Information campaign

A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, after analysing these sections, concluded that the only affected point by the adoption of MegaTrucks is the first one. In that observation, the parameters were listed in a table with their consequences:

Table 7.3 – Variation on safety in tunnels

Parameter	Variation with MegaTrucks
Intensity inside the tunnel	Positive
Congestion risk	Positive
Presence of heavy vehicles in the tunnel	Less percentage of heavy vehicles, but more risk when one vehicle is inside
Dangerous goods	Depending on the type of cargo, same effect as above. (however, LHV are not designed to carry chemical or dangerous goods)
Maximum speed	Neutral (MegaTrucks are limited to the same speed as regular trucks)
Geography and climate	In adverse weather problems might occur

Source: A. Ortega, J.M. Vassallo and P.J. Pérez – Martínez, "*Efecto de la implementación del MegaTruck de 60 toneladas en España",* 2011

- **Security barriers:**

According to "*Orden Circular 35/2014*", the conditions for the security barriers are defined in order to resist the impact.

In order to use a safety approach, only the barrier defined as "very high" will be considered for MegaTrucks. According to the study "*Longer and Heavier Vehicles in practice*", the maintenance costs increased from 3,39€/km up to 5,08€/km in Dutch highways (this value has been used in section 6).

8. Safety simulation VISSIM

8.1 Introduction

As exposed in the previous sections safety is an issue of matter when implementing a new technology, not only in Spain but in the entire Europe. In the past 5 years the average annual fatalities in Europe reached the undesirable number of 31.100 victims. Even though this trend is decreasing every year, more focus should be put on road safety.

Data on accidents and behaviour involving MegaTrucks is very scarce. There is no data form Spain because LHVs are not implemented yet (only a single trial in an open road) and the data form other countries in Europe are relatively weak due to the low number of vehicles and / or accidents. Also, it is hard to determine if there is a relationship between data from other countries and Spain.

Therefore, new methods for assessing the change in traffic safety in Spain have to be used. In order to predict how other road users would change their behavior and, thus, the safety of the network, a micro - simulation software has been used. The idea of using this simulation is being able to state if the collective safety of the road network is affected in a negative way, in a positive way, or if the adoption of MegaTrucks has no impact on the safety, so a neutral impact. By comparing different data obtained in different scenarios it will be possible to give an answer on the future collective safety on road network.

The software chosen to perform the simulation was PTV VISSIM 8.0. This software is a microscopic simulation program developed by PTV VG in 2015, in Karlsruhe, Germany, for multimodal transport operations. The software is time step oriented and behavior based simulation for modelling traffic on the roads. The traffic flow is simulated under various conditions and constraints of lane distribution, vehicle composition, relative density of type of vehicle or geometry of the road infrastructure.

The traffic flow model is based on a car-following model (for the modelling of driving in a single lane) and on a lane changing model. The software also gives the option to use traffic light signal control model for the traffic – dependent control logic units, but this tool was not necessary in order to represent the case. The car following model had been calibrated through multiple studies at the institute of transport studies of the Karlsruhe Institute of Technology, Germany.

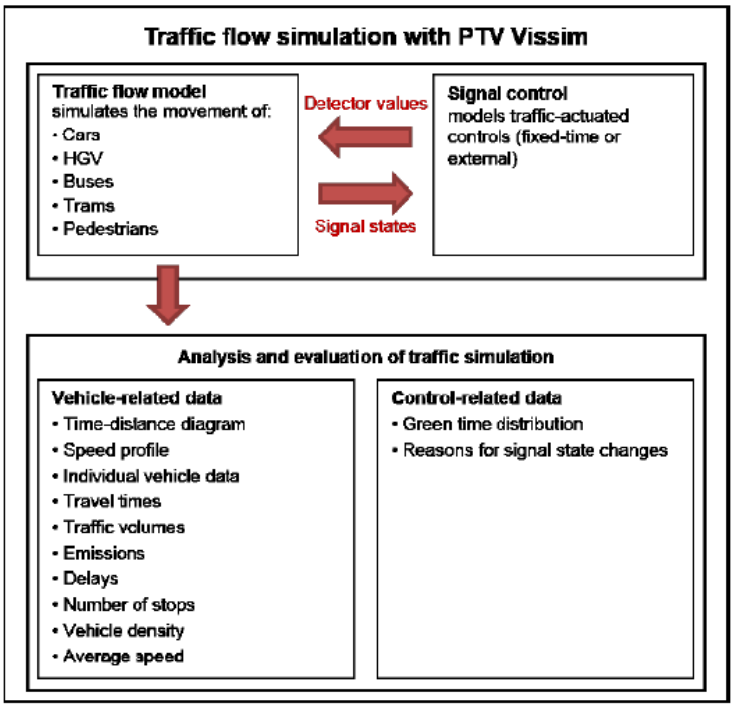


Figure 8.1 – Operating principles of the car following model in VISSIM 8
Source: PTV VISSIM user manual

For a multi – lane roadway a driver in the VISSIM model takes into account 4 vehicles ahead (default parameter) and also the vehicles in two adjacent lanes. Since MegaTrucks in Spain are only allowed to drive mainly in highways, the choice of VISSIM for representing a roadway with several lanes and multiple vehicles was an appropriate option.

VISSIM simulates the traffic flow by displacing several driver – vehicle – units through a road network. Each specific vehicle in the network is assigned with specific driver behavior characteristics. As a consequence of this distribution, each driving behavior corresponds to the technical capabilities of that vehicle.

The attributes characterizing each vehicle unit can be subdivided as follows:

- *Technical specification of the vehicle, for example:*
  - *Vehicle length*
  - *Maximum speed*
  - *Accelerating power*

and:

  - *Actual vehicle position in the network*
  - *Actual speed and acceleration*

- *Behavior of driver-vehicle units, for example:*

- *Psycho-physical perception thresholds of the driver, e.g. ability to estimate, perception of security, willingness to take risk*
- *Driver memory*
- *Acceleration based on current speed and driver's desired speed*

- *Interdependence of driver-vehicle units, for example:*

  - *Reference to vehicles in front and trailing vehicles on own and adjacent lanes*
  - *Reference to currently used network segment and next node*
  - *Reference to next traffic signal*

Source: VISSIM user manual, PTV AG, 2015 Karlsruhe, Germany

The behavior of driver – vehicle units is defined in three main components: Physiology, Subjective and Performance, exposed in the figure below:

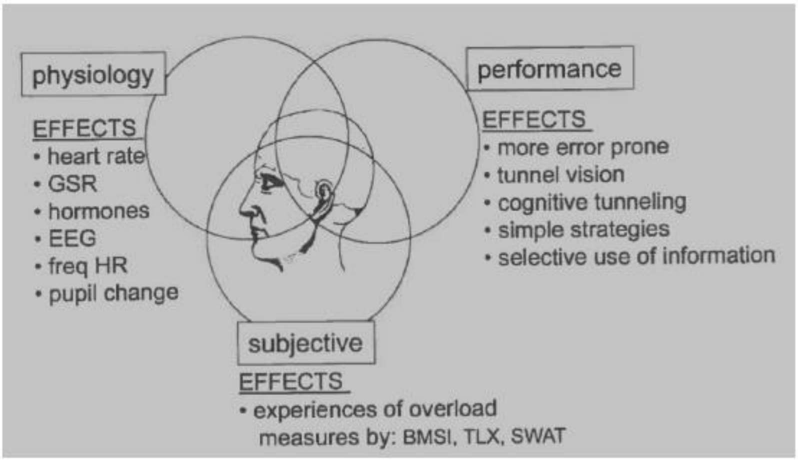


Figure 8.2 – Components of workload on the behaviour of the driver
Source: Theeuwers, et al. 2012

Different experiments and measures have been taken in order to introduce them in VISSIM for creating each vehicle unit.

The software has been downloaded via TU – DELFT (Technische Universiteit Delft). However, it was only possible to download the student version of the software and not the full version.

8.2 Selection of the highway

The scenario that was developed corresponds to a segment of a highway; concretely, the exit 19 in the Catalan tram of AP-7. This segment corresponds to the tram Montmeló – Papiol. The choice of this segment was not arbitrary. First of all, Catalunya is the autonomous community that has a larger number of fatalities. Concretely, 25,5% of the accidents in Spain were in that region (according to "*Abertis Autopistas*").

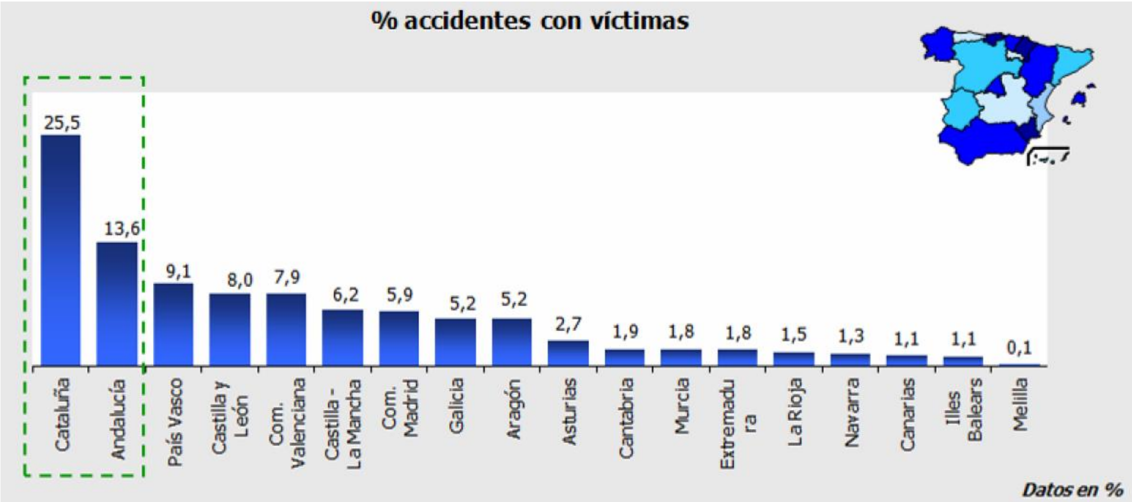


Figure 8.3 – % of fatalities by autonomous community
Source: Abertis Autopistas

Secondly, this tram in particular is the one that has the highest average daily intensity in terms of total vehicles and also in term of Heavy Good Vehicles, according to the data from EPTMC. The tables above show these values:

Table 8.1 – Total average daily intensity according to different trams

	TOTAL Av. daily intensity				
	Montmeló – La Junquera	Montmeló - Papiol	Barcelona - Tarragona	Tarragona - Valencia	Valencia - Alicante
2005	44.918	111.354	60.342	23.482	28.180
2006	47.122	115.607	63.683	25.215	29.207
2007	49.180	118.519	66.217	25.110	29.411
2008	46.761	114.760	61.694	22.155	26.180
2009	44.214	109.766	57.556	19.723	22.928
2010	43.522	108.967	54.825	20.091	21.445
2011	41.656	107.210	51.856	18.833	20.831
2012	39.166	103.289	47.589	16.528	17.691
2013	39.479	99.900	45.911	15.538	16.273
2014	41.718	101.976	46.888	15.797	16.304
2015	43.949	105.284	49.860	17.325	17.086

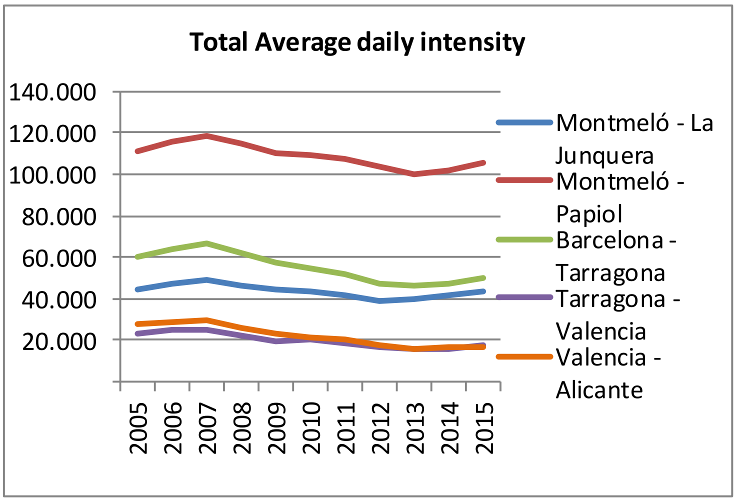
Source: Own elaboration, with values from ministerio de fomento

Table 8.2 – THGV average daily intensity according to different trams

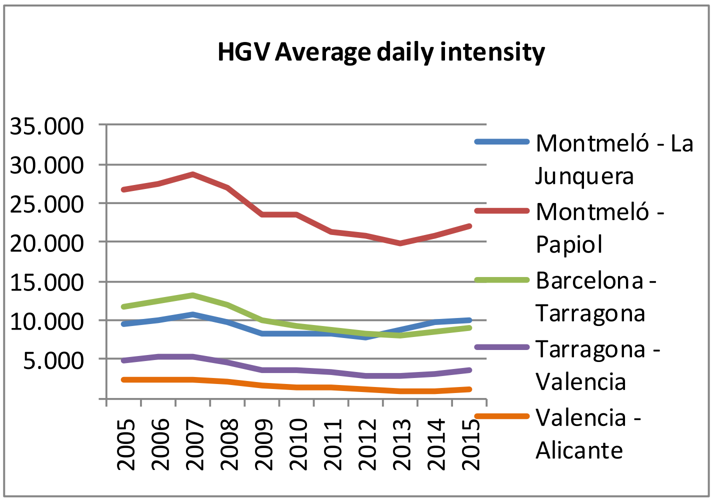
	HGV Av. daily intensity				
	Montmeló – La Junquera	Montmeló - Papiol	Barcelona - Tarragona	Tarragona - Valencia	Valencia - Alicante
2005	9.620	26.684	11.733	4.736	2.364
2006	10.011	27.369	12.433	5.267	2.445
2007	10.654	28.769	13.125	5.454	2.433
2008	9.809	26.853	11.872	4.676	2.065
2009	8.327	23.606	9.904	3.627	1.548
2010	8.207	23.445	9.179	3.582	1.388
2011	8.171	21.374	8.847	3.408	1.290
2012	7.788	20.739	8.228	2.967	1.088
2013	8.775	19.860	8.064	2.769	1.009
2014	9.718	20.823	8.450	3.033	1.033
2015	10.110	22.017	9.070	3.542	1.056

Source: Own elaboration, with values from ministerio de fomento

The tables above are clearer in the following figures:



a



b

Figure 8.4 – a) Total average daily intensity. b) HGV average daily intensity, according to different trams
Source: Own elaboration with values from Ministerio de Fomento

As it is possible to observe, the maximum values for the daily intensity are found in the tram between *Montmeló* and *El Papiol*. The total daily intensity clearly doubles the average intensity from the second tram. Therefore, the HGV daily intensity (as it is deductible) is also higher in that tram. This situation lead us think that this tram has the most potential risk regarding the adoption of LHVs, mainly because there are more vehicles and also because the percentage of heavy vehicles is higher in that tram:

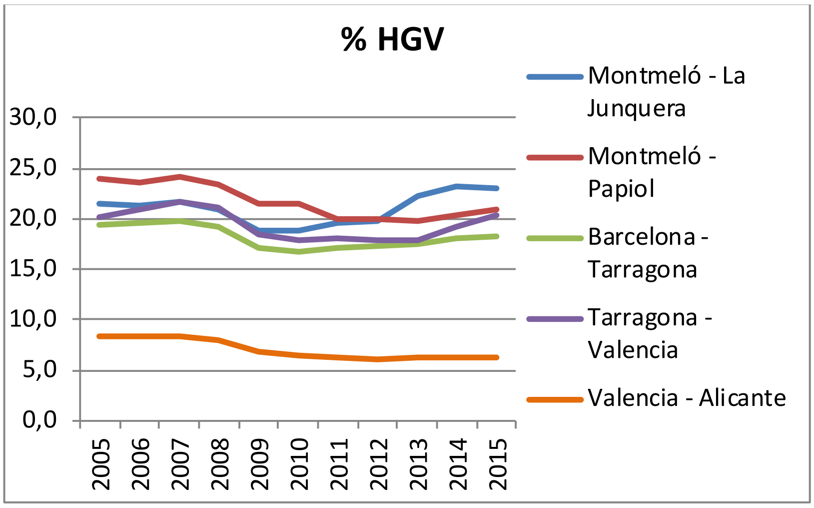


Figure 8.5 – Percentage of heavy vehicles in each tram
Source: Own elaboration with values from Ministerio de Fomento

It is true that within the last few years the tram Montmeló – Papiol decreased slightly the percentage of HGV, while in the tram between Montmeló and La Junquera increased. However, the difference between them is quite insignificant regarding the huge difference in the average daily intensity. For these reasons exposed above, a section in the tram Montmeló – Papiol was chosen.

Since the license obtained from the TU Delft was the student version, one of the main limitations was a reduced scale. The maximum scale that could be used was 1 kilometre. Therefore, a section of 1 kilometre in that tram was chosen. This section included exit 19 in the highway. The reason for that is the existence of a supermarket of the chain MAKRO, so potential users of MegaTrucks in a future. Also, steel and scrapping vehicle companies are present nearby, also companies that might get profit of the use of LHV.

Figure 8.6 – Location of companies susceptible to use MegaTrucks at the chosen location
Source: Google maps

Figure 8.7 – Position of the chosen location
Source: Google maps

a b

Figure 8.8 – a) Detailed position of the chosen location. b) Loading a MegaTruck with crates of beer
Source: Google maps and LHV in practice

8.3 Simulation

8.3.1 Scenario 1 – Actual situation

That particular segment has 4 lanes per direction, with an actual average daily intensity of 105.284 vehicles which 22.017 are HGV, representing 20,9%. The desired speed decisions of the drivers was considered to be the highest allowed speed in that highway, 120 km/h for cars and 90 km/h for HGV. Existence of public transport such as buses was neglected for this study.

The road network was designed in VISSIM, setting the links and the connectors directly on the image in order to obtain an exact model at the correct scale.

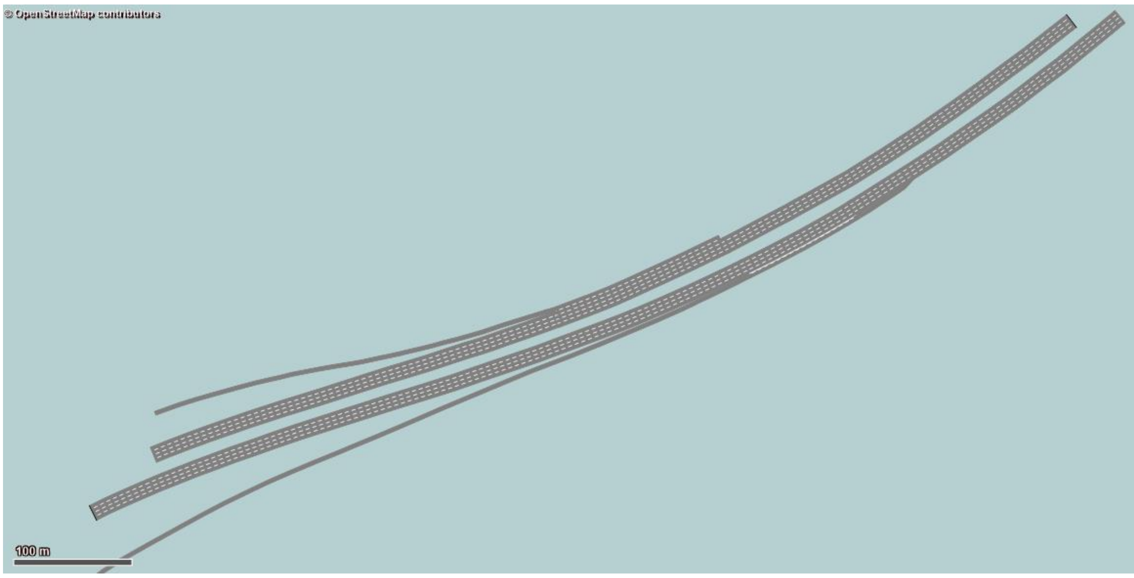


Figure 8.9 – Design of the network
Source: Own elaboration from VISSIM

Figure 8.10 – Design of the network
Source: Own elaboration from VISSIM

Once the road is designed, the input vehicles can now be introduced. VISSIM asks for the hour intensity. Considering a safe approach, the hourly intensity will not only be the daily intensity divided by 24. According to TU Delft, Transport and Planning section, professor Dr. Haneen Farah, 2016, a factor 1,2 will be used in order to consider some variations during the day and the night. With all these factors, and in order to make a simplification, a total intensity of 5.000 vehicles per hour will be used, with a percentage of 21% of heavy vehicles.

The current normative will be used for the rules regarding the simulation. Therefore, the highway will be defined with the left - side rule, and Heavy Goods Vehicles will not be able to circulate in the lane on the left. Regarding the determination of the on – ramp, the priority (as it might be obvious to think) will be given to the highway lanes.

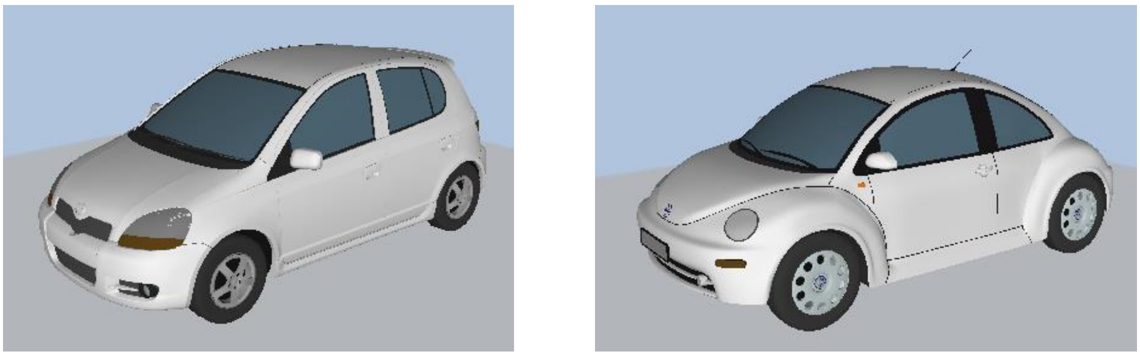
For this first scenario (actual situation) the 3D models used were only cars and regular trucks. There was need for adding new 3D models such as MegaTrucks. In order to give more reality to the simulation, the variable “car” in the simulation was composed out of 7 different models of cars. Also motorbikes will be introduced (included in the 79% of cars intensity). The different car models can be found below:

Count: 7	Share	Model2D3D
1	0,240	1: Car - Volkswagen Golf
2	0,180	2: Car - Audi A4
3	0,160	3: Car - Mercedes CLK
4	0,160	4: Car - Peugeot 607
5	0,140	5: Car - Volkswagen Beetl
6	0,020	6: Car - Porsche Cayman
7	0,100	7: Car - Toyota Yaris

a

b

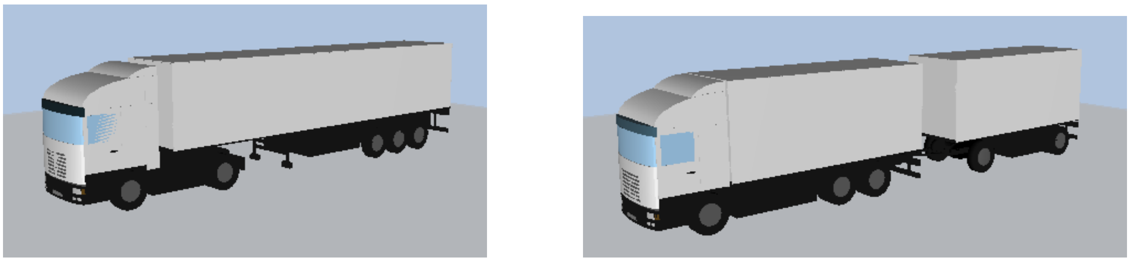
Figure 8.11 – a) Composition of the variable “car”, b) 3D model of Audi A4
Source: Own elaboration from VISSIM



a b

Figure 8.12 – a) 3D model of Toyota Yaris b) 3D model Volkswagen Beetle
Source: Own elaboration from VISSIM

For regular trucks, two main configurations were used, a tractor with a trailer reaching 18,75 meters and another shorter, combining a truck with a shorter trailer.



a b

Figure 8.13 – Components of the variable "truck" a) 3D model of a long trailer, b) 3D model of a trailer
Source: Own elaboration from VISSIM

Once all the variables and vehicles were defined, it is possible to run the simulator. As said in section 7.1 the main parameters of interest are the speed profile, the headway, the number of lane changes, the acceleration and the lateral position. These parameters were possible to be obtained as output when running the simulation. VISSIM gives as an outcome a file.FZP, which can be opened as a text file. Since the student version has some limitations, the maximum time of simulation is restricted up to 600 seconds (10 minutes).

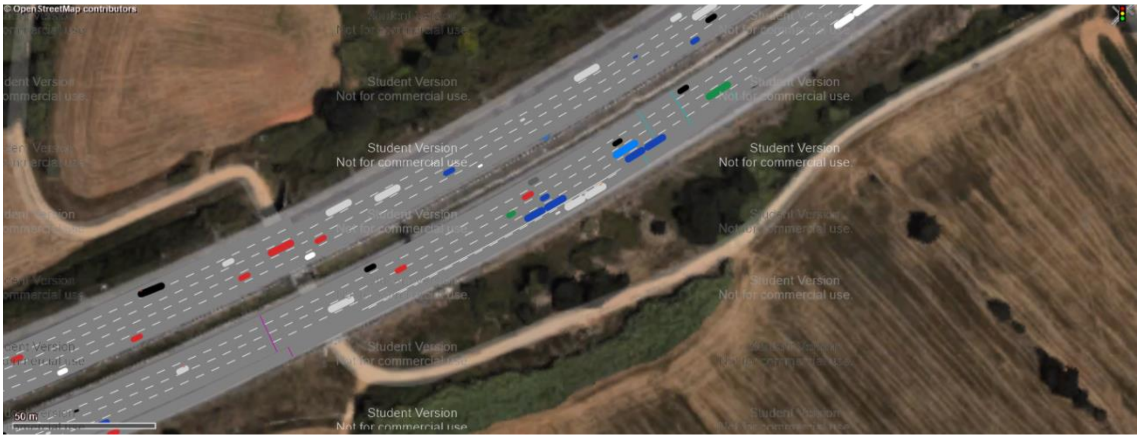
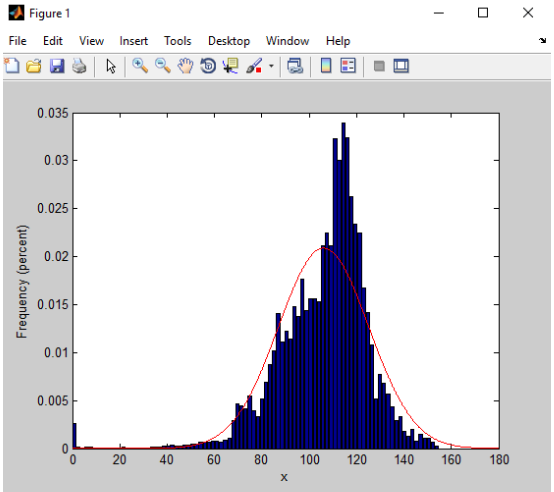
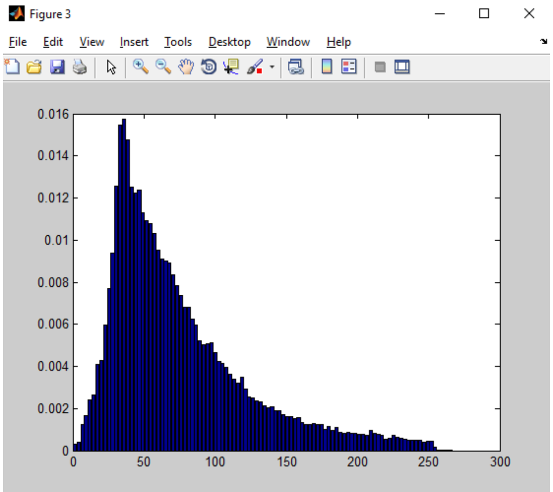


Figure 8.14 – Screenshot of the simulation while running (See Annex 5 for more screenshots)
Source: Own elaboration from VISSIM

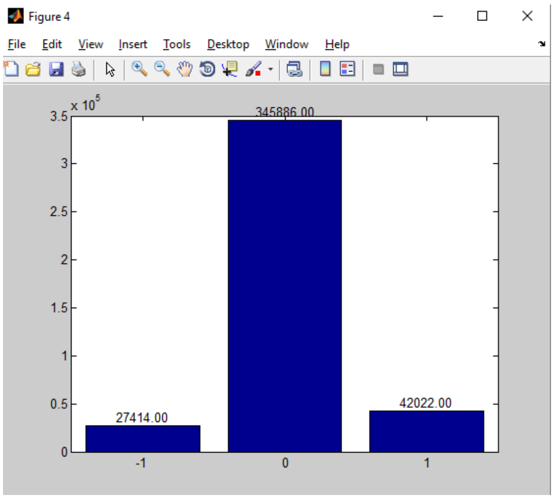
The obtained results were later plotted in MatLab. Per each simulated vehicle a total number of 500 observations were given (in Annex 6 it is possible to see the format of the outcome of VISSIM). This led us to a total number of 750.000 rows with different observations. However, this scope can already give us an idea of the safety with the adoption of MegaTrucks. The obtained results are given below:

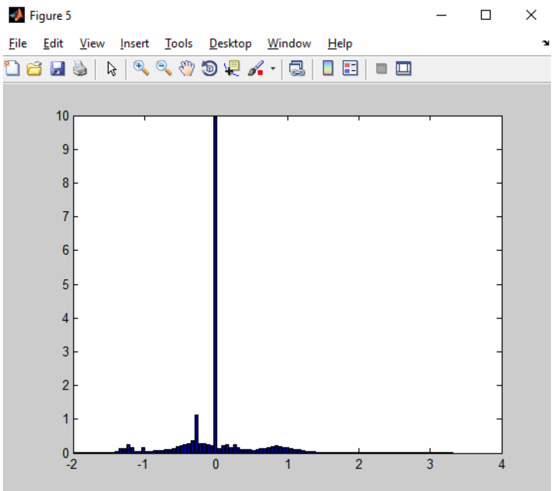




a) Speed mean = 106,08 km/h
Speed variance = 19,103 km/h
Speed mean of cars = 110,467 km/h
Speed variance of cars = 17,57 km/h
Speed mean of trucks = 91,89 km/h
Speed variance of trucks = 16,9 km/h

b) Headway mean = 74,98 m
Headway variance = 48,8 m
Headway mean cars = 78,8 m
Headway variance cars = 51 m
Headway mean trucks = 64,1 m
Headway variance trucks=38,3 m





c) Left changes = 27.414
No changes =345.886
Right changes = 42.022
Right change cars = 36.992
Left change cars = 24.990
Right change truck = 5.030
Left change trucks = 2.424

d) Acceleration mean = - 0,03 m/s²
Acceleration variance = 0,506m/s²
Acceleration mean cars=0,02m/s²
Acceleration mean trucks=-0,21m/s²
Acceleration variance cars=0,4m/s²
Acceleration variance trucks=0,5m/s²

Figure 8.15 - Scenario 1 a) Speed profile, b) Headway profile, c) Lane changes, d) Acceleration profile
Source: Own elaboration from VISSIM and MatLab

Furthermore, a total of 49.093 observations were laterally positioned at the right of the centre axle of the lane, 41.685 at the left while 324.544 vehicles were driving in the middle of the lane. However, this last observation is not that representative as the others ones, since when performing a lane changing manoeuvre the vehicles have to be displaced from the centre axis of the lane.

From the actual situation scenario simulation we can observe the plots and give some notes. The mean speed of the cars is a little bit lower than the desired speed decision (110,467 km/h). However, the variance of this value is quite high (17,57 km/h). When looking at the speed profile of trucks, with a similar value for the variance, the mean is around the desired speed decision. A high variance in the truck speed profile is more dangerous than the same order of the variance for the cars distribution. Also, since the average of the speed for the trucks is 91,89 km/h, it is possible to conclude that some trucks are circulating above the maximum speed limit for them.

When looking at the headway plot we can directly see that the car variance is very large in comparison with the average value, so the average is not that representative. On the other hand, trucks are more equally distributed.

The lane change chart indicates that the most number of vehicles do not change lane during the running time. However, when looking closely at the lane changes per vehicle type, one can observe that the most of the lane changes are performed by cars and not by trucks, a factor that might play a role when comparing the different scenarios.

For the acceleration profile fewer conclusions can be taken. Most of the cars do not accelerate either break. Also, most of these accelerations occur at the on ramp and of ramp locations, where cars and trucks must change their speed to 90 km/h and 70 km/h respectively in order to follow the normative.

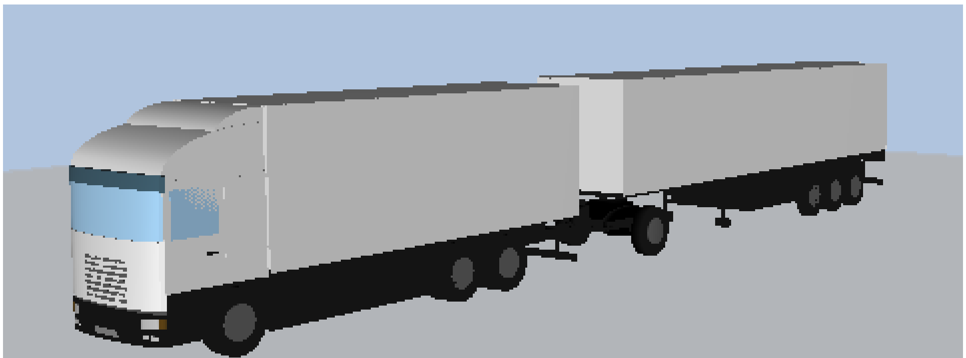
Also because of this, the speed profile and the other variables might be affected. However, one might note that the most effect of the on and off ramp is on the acceleration due to the fact that in terms of relative variation, the variation of speed is lower than the variation of acceleration.

8.3.2 Scenario 2 – 100% MegaTrucks

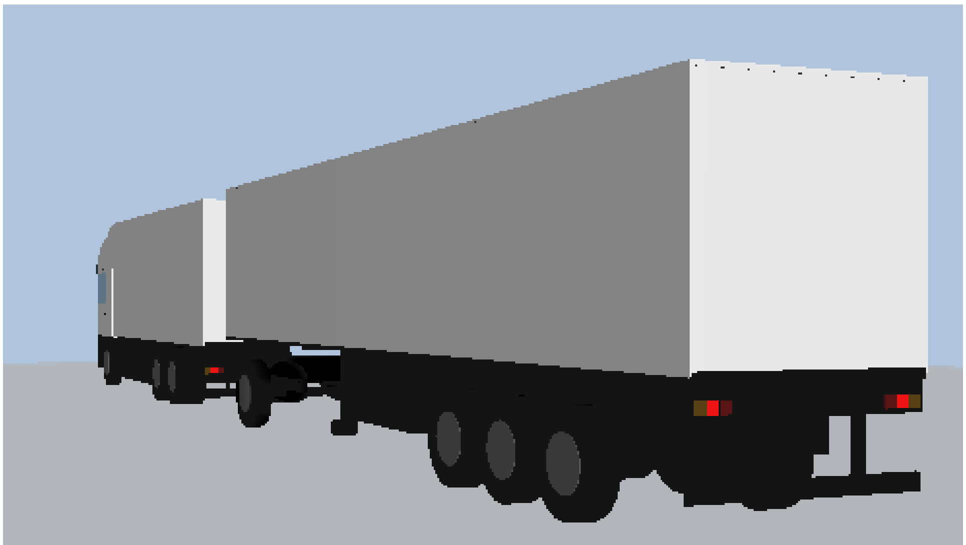
In this hypothetical scenario the introduction of a MegaTruck is already a fact. In this second scenario 100 % MegaTrucks has been supposed (instead of regular trucks). Of course this is a hypothetical scenario in order to compare with the completely contrary case the actual situation. In reality, this option might not be true due to the fact that the totality of the trucks will never be changed by MegaTrucks but only a fewer percentage.

The intention of this scenario is to give an answer to some studies where it is stated that a network full of MegaTrucks will be more dangerous than the actual situation.

In this scenario a new 3D model has been used in order to create a MegaTruck (MegaTrucks are not defined yet because they are not fully developed). The 3D model of a MegaTruck was created the most similar according to configuration D (see section 2.1).



a



b

Figure 8.16 – Components of the variable "MegaTruck" a) lateral view of a MegaTruck 3D model, b) Rear view of a MegaTruck 3D model
Source: Own elaboration from VISSIM

In this second scenario the intensity of the cars has been considered unaffected by the introduction of MegaTrucks. Therefore, only the 21% of the initial average hourly intensity has been modified. As a simplification, it has been taken that the relationship between regular trucks and MegaTrucks is 2 MegaTrucks = 3 regular trucks. This consideration is not actually true at 100% due to the fact that the total weight (60 tonnes and 40 tonnes respectively) is not governing at all but the total load is. Considering the total load capacity (39 tonnes and 25 tonnes respectively), a relationship of 0,64 MegaTrucks = 1 regular truck is obtained. However, as a simplification, the first relationship has been used also because the difference is really low and can be neglected.

In scenario 2, with 100% of LHVs, the percentage of heavy vehicles reduces to 15% (while the cars are now representing 85%). Note that the total intensity of the variable "car" is the same, but its percentage due to a reduction of the number of heavy vehicles reduces.

According to the regulation approved by "*Dirección General de Tráfico*" from April 2016, Longer and Heavier Vehicles will have a maximum speed limit of 90 km/h in highways, 80 km/h in conventional roads with a safety lane of 1,5 metres and 70 km/h in other interurban roads (same as regular trucks). These restrictions have been introduced to VISSIM. Same as regular trucks, LHV will have the restriction to not circulate on the lane on the left.

The simulation is run again with this second scenario.

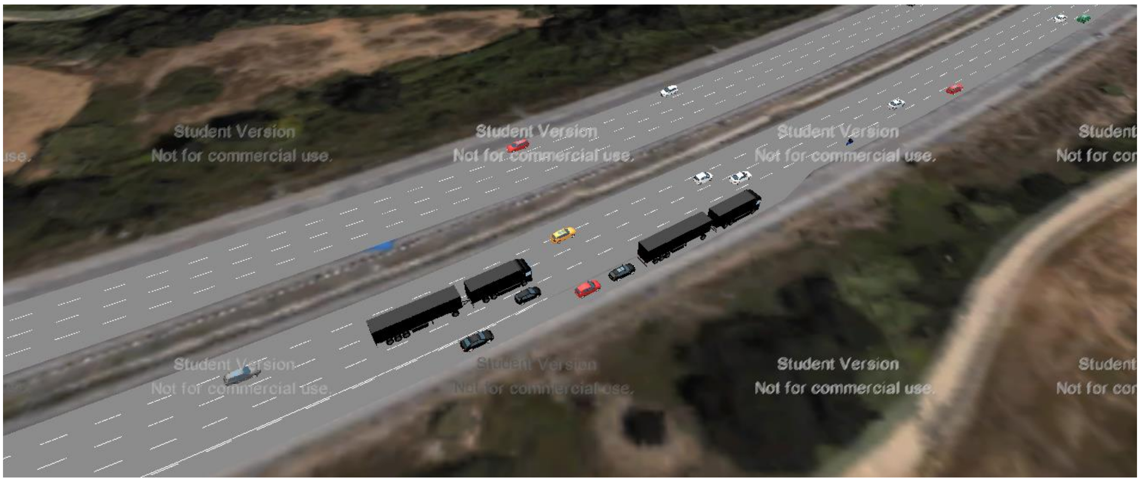
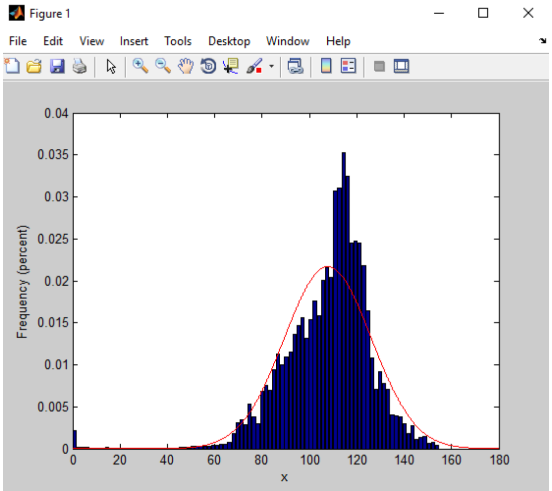
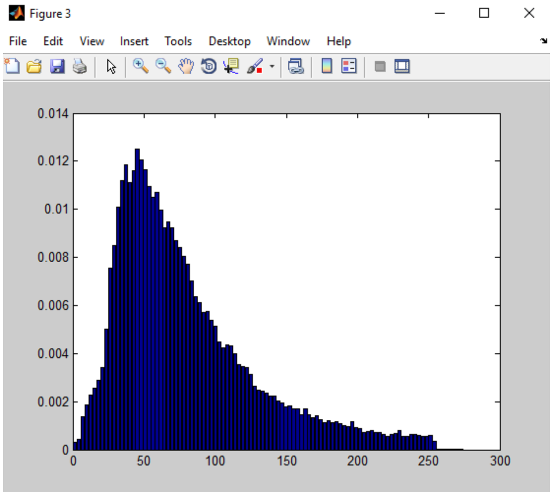


Figure 8.17 – Screenshot of the simulation while running with 2 MegaTrucks
Source: Own elaboration from VISSIM

In the figure above it is possible to see already two MegaTrucks circulating on the simulation.

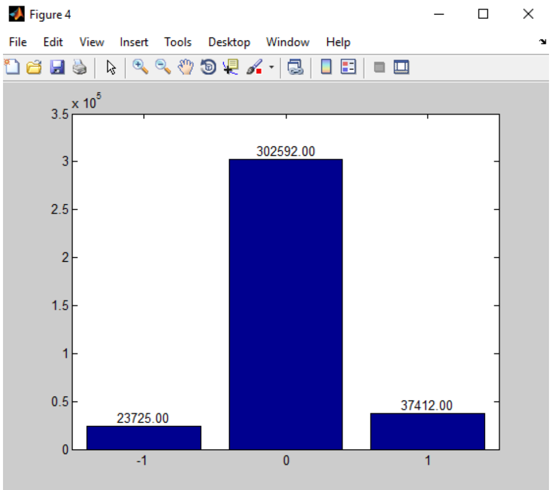
The obtained results for scenario 2 are given below:

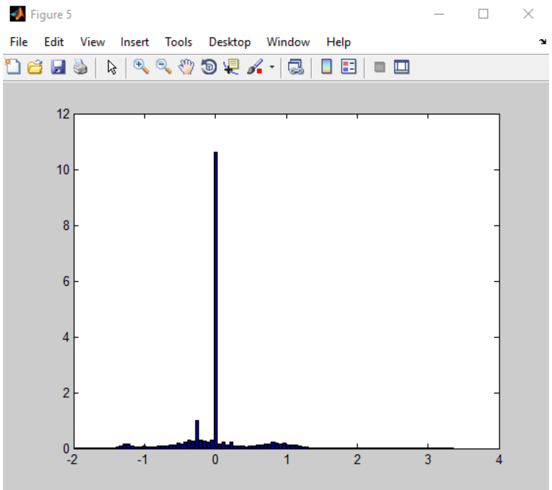




a) Speed mean = 107,76 km/h
Speed variance = 18,39km/h
Speed mean of cars = 111,25km/h
Speed variance of cars = 16,64km/h
Speed mean of MT = 91,55km/h
Speed variance of MT = 16,58 km/h

b) Headway mean = 79,54m
Headway variance = 49,7m
Headway mean cars = 82,59m
Headway variance cars = 51,68m
Headway mean MT = 70,98m
Headway variance MT =39,2m





c) Left changes = 23.725
No changes = 302.592
Right changes = 37.412
Right change cars = 33.757
Left change cars = 22.620
Right change MT = 3.655
Left change MT = 1.105

d) Acceleration mean = - 0,00830 m/s^2
Acceleration variance = 0,4856m/s^2
Acceleration mean cars=0,0266m/s^2
Acceleration mean MT = -0,184m/s^2
Acceleration variance cars=0,46m/s^2
Acceleration variance MT =0,52m/s^2

Figure 8.18 - Scenario 2: a) Speed profile, b) Headway profile, c) Lane changes, d) Acceleration profile
Source: Own elaboration from VISSIM and MatLab

When observing at the results from the scenario one it can be concluded that the main changes have been produced in the cars and not in the trucks. The speed mean for cars shows a slightly difference from scenario one (higher in that second scenario). At the same time that the variation shows a decrease in its value, a fact that implies that not only the cars are approaching more to its desired speed decision but they are doing it in a more distributed way without many speed variations.

Regarding the headway, it is possible to say that the mean headway regarding cars and regarding MegaTruck have both increased, keeping the same value for the variation. About the lane changes, in general, the total number of lane changes decreased as well for both types of vehicles. Also, the acceleration decreased with this new scenario.

8.3.3 Scenario 3 – 30% MegaTrucks:

This third scenario is a more realistic scenario than the previous one. Here, the adoption of LHVs is a fact but only achieving 30% of the total heavy vehicles on the road. This situation might be more realistic in a future rather than in a short period of time, since the implementation of MegaTrucks would be a progressive process instead of an immediate adoption. For the calculation of the new percentages, the total number of cars has remained the same. On the other hand, with the total number of trucks, 30% of them has been reduced using the relationship exposed above 2 MegaTrucks = 3 trucks, while the other 70% has remained the same as well. With these new total values, the variable "car" will represent 81% of the total intensity; regular trucks will represent 15% and MegaTrucks 4%. However this scenario has a limitation that should be exposed. It is true that that case is more realistic than the second scenario. Nevertheless, to achieve a market share of 30% for MegaTrucks it is necessary to wait more time and not expect this scenario to be adopted in a short period of time. In that larger period the composition of the traffic flow might change, leading to some changes in the percentages shown above. In order to simplify the simulation, the same intensity as the actual situation for cars has been used without considering the changes that might arise in a future. The results of this scenario with 30% MegaTrucks are exposed below. Note that in this case there are cars, regular trucks and MegaTrucks.

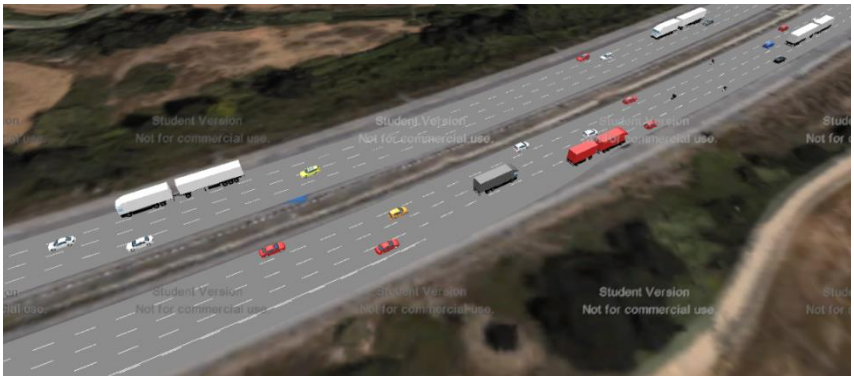
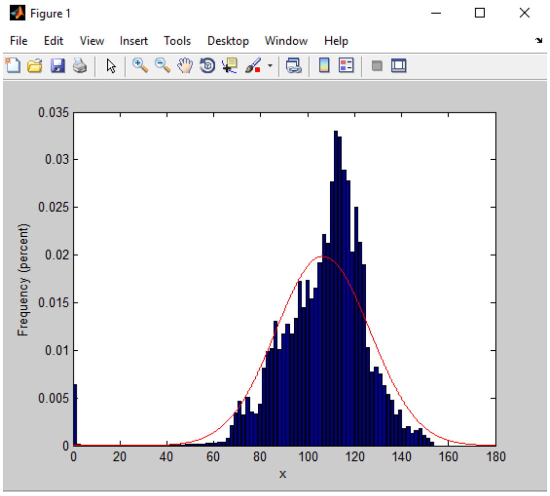
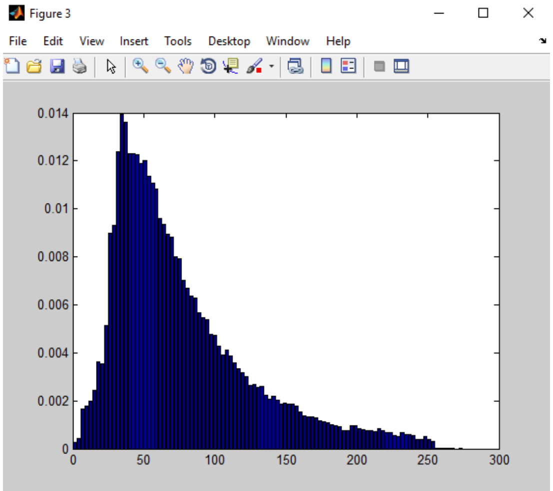


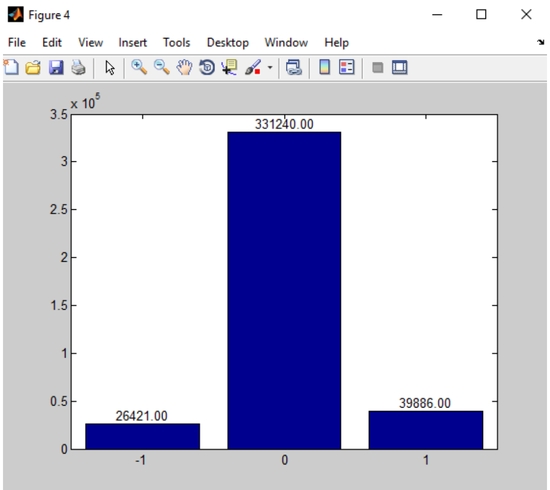
Figure 8.19 – Screenshot of the simulation while running MegaTrucks and regular trucks
Source: Own elaboration from VISSIM

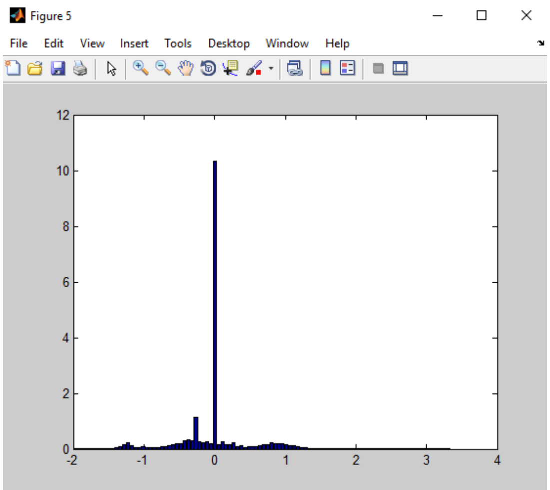




a) Speed mean = 106,5 km/h
Speed variance = 20,08 km/h
Speed mean of cars = 111,32km/h
Speed variance of cars = 16,95km/h
Speed mean truck = 92,55km/h
Speed variance truck =16,06km/h
Speed mean of MT = 83,02km/h
Speed variance of MT = 32,19km/h

b) Headway mean = 76,8m
Headway variance = 49,04m
Headway mean cars = 80,47m
Headway variance cars = 51,44m
Headway mean truck = 65,97m
Headway variance truck =38,08m
Headway mean MT = 63,03m
Headway variance MT = 38,25m





c) Left changes = 26.421
No changes = 331.240
Right changes = 39.886
Right change cars = 35.838
Left change cars = 24.839
Right change truck = 2.996
Left change truck = 1.221
Right change MT = 1.052
Left change MT = 361

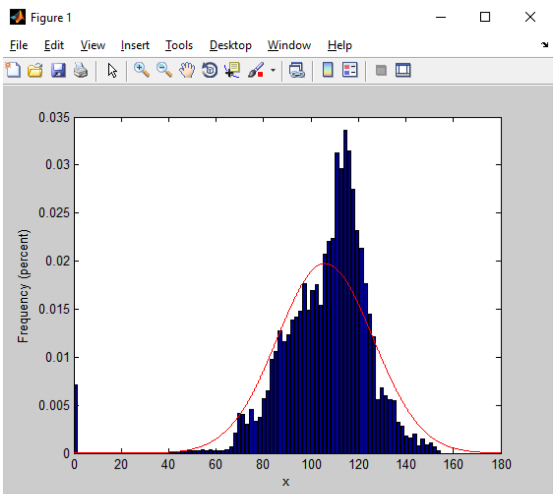
d) Acceleration mean = -0,03m/s²
Acceleration variance = 0,47m/s²
Acc. mean cars=0,022m/s²
Acc. variance cars=0,47m/s²
Acc. mean truck = -0,2m/s²
Acc. variance truck =0,5 m/s²
Acc. mean MT = -0,22m/s²
Acc. Variance MT = 0,49m/s²

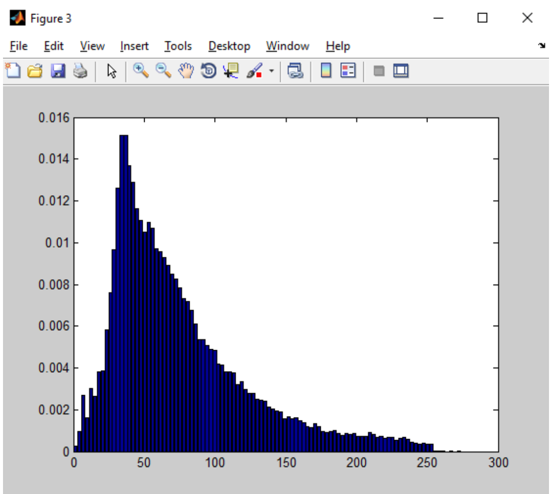
Figure 8.20 - Scenario 3: a) Speed profile, b) Headway profile, c) Lane changes, d) Acceleration profile
Source: Own elaboration from VISSIM and MatLab

8.3.4 Scenario 4 – 5% MegaTrucks:

To finish the simulation, a last scenario with only 5% of MegaTrucks was considered. The aim of performing this scenario with only that little number of LHV is to observe the behaviour of the network and the collective safety just after its implementation, where the percentage of MegaTrucks would still be low. Therefore, in this scenario the variable car represented 79%, the variable regular truck 20% and MegaTruck 1% of the total hourly intensity.

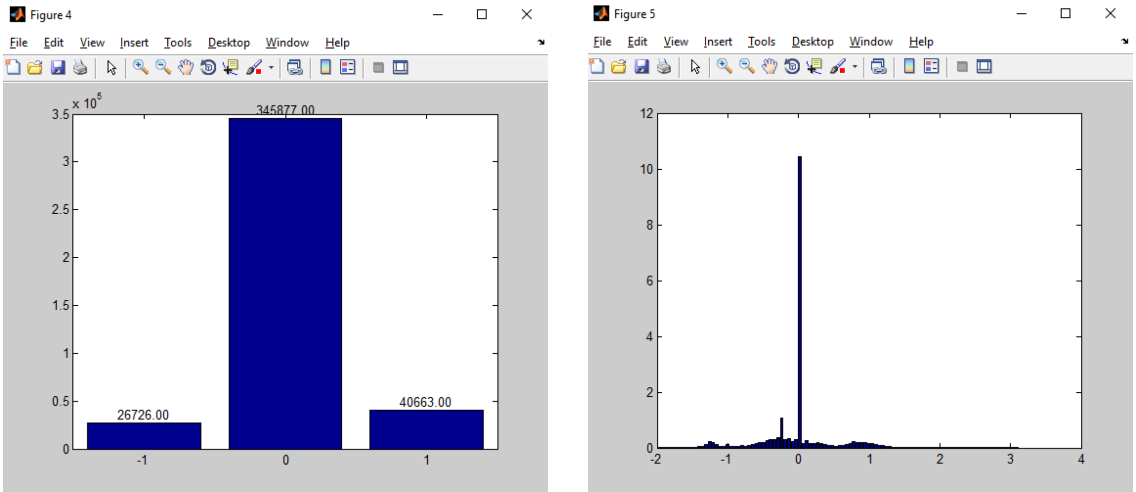
Proceeding with the same way as the other scenarios, the intensity for cars has remained the same, only changing 5% of the total number of trucks to MegaTrucks. This scenario does seem more realistic due to the fact that after the implementation of LHV the total intensity might not be affected that much.





a) *Speed mean = 105,9 km/h*
Speed variance = 20,19 km/h
Speed mean of cars = 110,2 km/h
Speed variance of cars = 19,24km/h
Speed mean truck = 91,7 km/h
Speed variance truck =18,86 km/h
Speed mean of MT = 91,1 km/h
Speed variance of MT = 16,53 km/h

b) *Headway mean = 75,29m*
Headway variance = 48,72m
Headway mean cars = 78,97m
Headway variance cars = 51,54m
Headway mean truck = 66,04m
Headway variance truck =38,07m
Headway mean MT = 64,74m
Headway variance MT = 32,0m



c) Left changes = 26.726
No changes = 345.877
Right changes = 40.663
Right change cars = 36.082
Left change cars = 24.940
Right change truck = 4.312
Left change truck = 1.761
Right change MT = 269
Left change MT = 25

d) Acceleration mean = -0,03m/s²
Acceleration variance = 0,49m/s²
Acc. mean cars=0,018m/s²
Acc. variance cars=0,47m/s²
Acc. mean truck = -0,21m/s²
Acc. variance truck =0,52 m/s²
Acc. mean MT = -0,19m/s²
Acc. Variance MT = 0,52m/s²

Figure 8.21 - Scenario 4: a) Speed profile, b) Headway profile, c) Lane changes, d) Acceleration profile
Source: Own elaboration from VISSIM and MatLab

Table 8.3 – Result of the simulation in the different scenarios

	Scenario 1 (Actual situation)			Scenario 2 (100% MT)		
	General	Car	Truck	General	Car	MegaTruck
Speed mean (km/h)	106,08	110,47	91,89	107,76	111,25	91,55
Speed variace (km/h)	19,10	17,57	16,90	18,39	16,64	16,58
Headway mean (m)	74,98	78,80	64,10	79,54	82,59	70,98
Headway variance (m)	48,80	51,00	38,30	49,70	51,68	39,20
Left changes	27.414	24.990	2.424	23.725	22.620	1.105
Right changes	42.022	36.992	5.030	37.412	33.757	3.655
Acceleration mean (m/s^2)	-0,03	0,02	-0,21	-0,008	0,03	-0,18
Acceleration variance(m/s^2)	0,51	0,40	0,50	0,49	0,46	0,52

	Scenatio 3 (30% MT)			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	106,50	111,32	92,55	83,02
Speed variace (km/h)	20,08	16,95	16,06	32,19
Headway mean (m)	76,80	80,47	65,97	63,03
Headway variance (m)	49,04	51,44	38,08	38,25
Left changes	26.421	24.839	1.221	361
Right changes	39.886	35.838	2.996	1.052
Acceleration mean (m/s^2)	-0,03	0,02	-0,20	-0,22
Acceleration variance(m/s^2)	0,47	0,47	0,50	0,49

	Scenario 4 (5% MT)			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	105,90	110,20	91,70	91,10
Speed variace (km/h)	20,19	19,24	18,86	16,53
Headway mean (m)	75,29	78,97	66,04	64,74
Headway variance (m)	48,72	51,54	38,07	32,00
Left changes	26.726	24.940	1.761	25
Right changes	40.663	36.082	4.312	269
Acceleration mean (m/s^2)	-0,03	0,02	-0,21	-0,19
Acceleration variance(m/s^2)	0,49	0,47	0,52	0,52

Source: Own elaboration

Once the total results were obtained, a table with the relative variation with the actual situation has been elaborated. With this table it is possible to compare each scenario with the actual situation and judge if the general safety of the road has increased or decreased.

Table 8.4 – Results of the simulation in terms of variation with the actual situation

	Scenario 2 (100% MT) Variation		
	General	Car	MegaTruck
Speed mean (km/h)	1,58%	0,71%	-0,37%
Speed variance (km/h)	-3,73%	-5,29%	-1,89%
Headway mean (m)	6,08%	4,81%	10,73%
Headway variance (m)	1,84%	1,33%	2,35%
Left changes	-13,46%	-9,48%	-54,41%
Right changes	-10,97%	-8,75%	-27,34%
Acceleration mean (m/s^2)	-74,85%	30,00%	-12,38%
Acceleration variance(m/s^2)	-4,03%	15,00%	4,00%

*MegaTruck compared with actual regular trucks

	Scenatio 3 (30% MT) Variation			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	0,40%	0,77%	0,72%	
Speed variance (km/h)	5,11%	-3,53%	-4,97%	
Headway mean (m)	2,43%	2,12%	2,92%	
Headway variance (m)	0,49%	0,86%	-0,57%	
Left changes	-3,62%	43,41%	-49,63%	
Right changes	-5,08%	-32,85%	-40,44%	
Acceleration mean (m/s^2)	-9,09%	10,00%	-4,76%	
Acceleration variance(m/s^2)	-7,11%	17,50%	0,00%	

*No comparison for MegaTrucks since these vehicles do not have any similar vehicle currently

	Scenario 4 (5% MT) Variation			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	-0,17%	-0,24%	-0,21%	
Speed variace (km/h)	5,69%	9,50%	11,60%	
Headway mean (m)	0,41%	0,22%	3,03%	
Headway variance (m)	-0,16%	1,06%	-0,60%	
Left changes	-2,51%	-0,20%	-27,35%	
Right changes	-3,23%	-2,46%	-14,27%	
Acceleration mean (m/s^2)	-9,09%	-10,00%	0,00%	
Acceleration variance(m/s^2)	-3,16%	17,50%	4,00%	

Source: Own elaboration

When looking at the variation tables some conclusions can be taken. Comparing first scenario 2 with scenario 1, it can be seen that the speed mean has a positive increment. That means that more vehicles can circulate (or at least approach more) at their desired speed, since in the actual situation the average speed was lower. At the same time, the speed variance is lower, a fact that in objective term means more safety to the road since the differences between speeds are lower as well.

When looking at the headway, fewer conclusions can be taken. The average headway increases in 6,08% (that is around 5 meters). However, it must be considered that the headway is a parameter that measures the distance between the front part of a vehicle with the front part of its predecessor. In this way, an increase of 5 meters at the mean is not that much if one considers that the vehicles included in this scenario are longer as well. Having this issue in mind, the headway is not affected at all, is not better but is not worse either.

Where there is a sustainable variation is at the number of lane changes. In scenario 2 the total number of changes clearly shows a decrease, a very positive issue when talking about safety. If there are less lane changes, there are less conflict points where vehicles can laterally collision with another car or truck. Also, it is good to see that the major amount of lane changes is performed by cars and not by trucks (or MegaTrucks). In the case of MegaTrucks, this fact is even more significant, where the lane changes reduce around 50%.

The percentage of the acceleration might bring some confusion. According to the results, they reduce in 74%. However, it is important to know where we come from. The actual acceleration mean has a value of -0,03 m/s^2 while in the scenario 2 has a value of -0,008 m/s^2. First, since the acceleration had a negative value, a decrease of the percentage means that the value for the acceleration in increasing, concretely approaching to 0 (which would be the best value). Nevertheless, the values for the acceleration are that small that any change would end up with a very high percentage for increment or decrease. What is more important in this parameter is that the value of the variation for the variance is decreasing. Less acceleration variance would end up in a safer environment for road used because the vehicles would change their speed less times.

When taking a look to scenario 4, the totally opposite one, one can conclude that the adoption of LHVs has almost no impact. It is true that the value for the average speed shows a decrease but, however, this decrease only accounts -0,17%. This implies that the average speed changes from 106,08 km/h to 105,9 km/h, so literally 0,18 km/h difference. This difference can completely be neglected when considering the road safety. As it is possible to observe, the other parameters show a similar behaviour when comparing Scenario 4 with scenario 1. Scenario number 3 is in between scenario 2 and 4. The results for that situation are in the middle of the values of the other 2, giving some benefits for the road safety such as less lane changes, more headway and acceleration closer to 0.

As a conclusion of this section, after comparing the results for each scenario, it is possible to state that the implementation of Longer and Heavier Vehicles only will have a positive impact on the collective road safety in a long term. As stated in scenario 2 with 100 % MegaTrucks, the parameters regarding the road network have a positive variation leading to a safer environment.

Scenario 4 has almost no change so, in a short time, the adoption of this new technique for road freight transport has a neutral effect on collective safety, but not negative. Therefore, to ensure a safe environment for other road users, more focus should be placed on improving the individual safety of these vehicles, since their individual risk might be the fact that raises the risk that many people fear when hearing about MegaTrucks.

8.4 Lane restriction for MegaTrucks:

Once the study of general behaviour has been done, the possibility to add a lane restriction for MegaTrucks has been considered. Lane changing conflicts are the most common conflicts when an accident happens. Also, when talking about MegaTrucks, the lane change manoeuvre as shown in table 2.2 in section 2.1 requires more space. Because of these factors the lane change manoeuvre is considered independently.

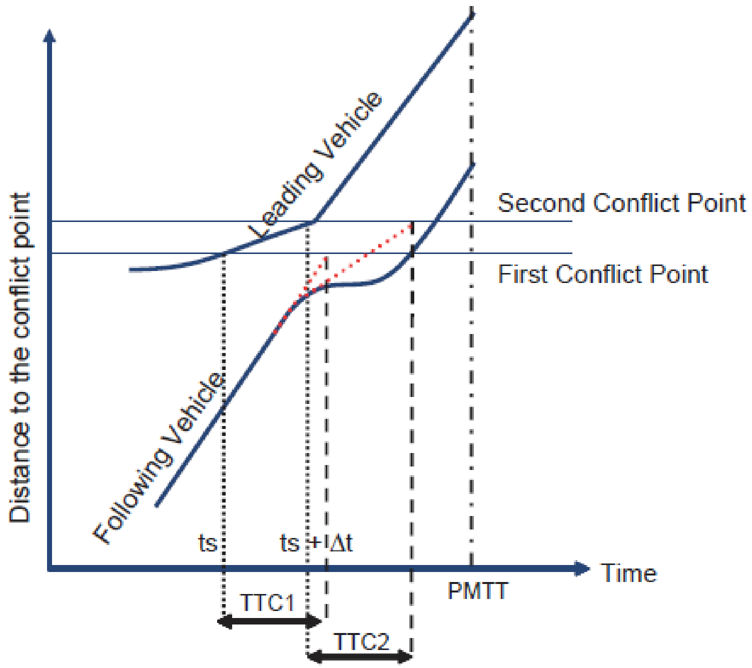


Figure 8.22 – Graphical description of the lane change conflict
Source: Samah El-Tantawy, Shadi Djavadian, Matthew J. Roorda, and Baher Abdulhai "*Safety evaluation of truck lane restriction*", 2009

The lane change conflict appears when a vehicle is making a lane change (the lading vehicle) into the lane of a following vehicle (as illustrated in figure 8.22). The curves in the figure represent the time – space trajectory of both vehicles. The tracing begins when the leading vehicles starts the manoeuvre. Applying this to LHVs, the distance to the conflict point should be higher to guarantee a safety environment.

Therefore, a new scenario is now considered where MegaTrucks are restricted only to circulate on the rightmost lane in highways. This scenario will be compared with the one with 30% MegaTrucks since is the most approximated to the future use of MegaTrucks.

The entire results can be found in Annex 8.

Table 8.5 – Results of the simulation in terms of variation with Scenario 3

	Scenario 3 (30% MT) lane restriction Variation with 3			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	-0,02%	-0,31%	-0,04%	4,02%
Speed variance (km/h)	-1,54%	3,72%	-4,79%	-48,65%
Headway mean (m)	-1,18%	-1,54%	-0,94%	0,27%
Headway variance (m)	0,08%	0,25%	-2,13%	-6,54%
Left changes	0,88%	-32,42%	-1,47%	-86,15%
Right changes	1,77%	41,33%	-11,01%	-93,06%
Acceleration mean (m/s^2)	-30,00%	0,00%	-6,00%	-16,36%
Acceleration variance(m/s^2)	4,26%	2,13%	4,00%	2,04%

Source: Own elaboration

In the table above the variation of the results of the scenario with a restriction on lane change with the scenario 3 are given. As it is possible to see, there is no change in the car and truck speed mean, indicating that the fact that MegaTrucks are driving only on the rightmost lane does not affect to their behaviour. However, there are some benefits for MegaTrucks itself, an increment of their speed mean and a decrease of the speed variance. That is mainly because since they are not allowed to change lane they cannot overtake any vehicle so the speed reaches a more uniform distribution.

The same behaviour is found with the headways. For cars and MegaTrucks the headway is not affected (note that the small decrease of headway might be due to the no presence of MegaTrucks in the middle lane, so the headway is not considering the length of the vehicle) while the headway variance of the restricted vehicles is reduced.

The higher difference is found, of course, in the number of lane changes. Car users change their behaviour and have less need to change lane to the left, probably because there is enough space for them to drive in the middle lane (with no MegaTrucks). Also, they increase the number of right changes. The lane restriction for MegaTrucks seems to affect the regular trucks, since they also reduce their number of lane changes in both directions. It does not need to be mentioned but the lane changes for MegaTrucks is lowered at the minimum, only accounting the values from the on and off ramp.

Acceleration, in general terms, is reduced a lot, meaning a lower speed variability. However this fact only applies for trucks and MegaTrucks, while cars do not experience any change.

These small effects can be explained with the fact that the vehicles that mainly change lanes are cars. In the previous scenario 3, without lane restriction, almost the totality of lane changes was performed by cars:

	General	Car	Truck	MegaTruck
Left changes	26.421	24.839	1.221	361 (1,37%)
Right changes	39.886	35.838	2.996	1.052 (2,64%)

Restricting the movement to that 1,37% and 2,64% would not affect that much to the rest of the users, while, of course, will increment the safety of the restricted vehicles. The question to answer is if it is worth for the government to restrict LHVs to the rightmost lane regarding the small effect on other road users considering the effects it will have to truck drivers. Hence, the answer to this question must be answered by the government, who should study this possibility. Nevertheless, and regarding the small percentage, it would be possible to recommend to not use this restriction since the small impact it will have.

9. Discussion and conclusions

The progressive increase on the limit of the weight and length of road freight transport vehicles has been clearly successful in improving road transport, reason why Longer and Heavier Vehicles have been studied carefully in this study. After analysing MegaTrucks as a future solution for an improvement in road efficiency is it possible to state some conclusions.

From the economic analysis it is an evidence that the operational costs per kilometre regarding MegaTrucks is larger than the operational costs per kilometre of a regular truck. Nevertheless, the operational costs per tonne · kilometre is lower in a MegaTruck. A similar fact occurs with emissions, a MegaTruck consumes more so it emits a higher number of gases but the ratio emissions / kilometre · tonne is lower. With these facts, when comparing an actual corridor with the use of these vehicles private investors would save around 16,34%. Though, to be able to reach that percentage of savings some requirements are necessary, such as keeping the ratio annual cargo trips – annual empty trips. It has been shown that with the actual norm published by BOE and DGT, MegaTrucks will have a tough implementation, since they are only allowed to circulate from point to point and not freely on the full network. This might end up in a reduction of cargo trips and an increase of the empty operations, where at the end the savings for the private investors were shown to be way lower, around 4%. If this regulation does not intent to change in the future years it is licit to think that private companies would not be that interested in investing in these vehicles due to the high risk it might imply, only saving 4% of the total costs.

After this study some recommendations of some measures can be given. It is recommended to simplify the procedure for issuing the circulation of LHVs. The actual normative states that every trip should be notified to DGT and be defined as especial transport. It would be more efficient that once the permission is given, it would apply to the entire fleet of vehicles instead of single trips.

Also, the restriction to circulate only from A to B clearly hinders the adoption of these vehicles. Most private companies are interested on transporting goods from their factory to the distribution locations. However, the other way trip is not that clear that will be efficient, since will not be possible to load the truck in its entire capacity. Since MegaTrucks are not allowed to follow other routes, a high weak point is found here. In a future, it would be recommended to consider this norm.

However, these percentages are calculated with an approximation of the costs of a MegaTruck; a further study with real values should be made in order to give a more precise percentage of saves.

The results of the other part of the study clearly show that the introduction of this new way of transport will not introduce in any extra collective risk. The road network behaves in a similar way with or without LHVs. Thus, it is possible to state that the introduction of this technology wills have a neutral effect on the road users. This is because, despite the fact that MegaTrucks are longer and heavier than regular trucks, less trucks are operating on the road. Therefore, the only higher risk induced by the use of MegaTrucks is the individual risk that they have compared with a regular truck.

To ensure and improve individual traffic safety some measures can be done such as providing support systems. For instance, visibility support will be helpful in order to ensure that the driver detects all the obstacles in the blind spots around the vehicle. In these trucks, the limitation of visibility might be a cause of a higher individual risk.

Finally, in order to check and validate all the data given in this study, a longer trial period should be planned in Spain. Following the example of other countries such as Sweden or The Netherlands, some trial test should be performed during some years collecting real data and studying the real effect of Longer and Heavier Vehicles in Spanish roads

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Annex

Annex 1 - BOE Orden PRE/2788/2015, 18th de December 2015

TEXTO

Los avances técnicos en el diseño de los vehículos de transporte por carretera y la mejora de las infraestructuras viarias de nuestro país permiten actualmente autorizar la circulación de determinados conjuntos de vehículos con unas masas y dimensiones superiores a las establecidas con carácter general, mejorando de esta manera la eficiencia y la seguridad en el transporte por carretera y permitiendo un funcionamiento más competitivo de los mercados, tal y como se recoge en el Plan de medidas para el crecimiento, la competitividad y la eficiencia, aprobado por el Consejo de Ministros el 6 de junio de 2014.

La normativa comunitaria contempla la posibilidad de establecer a nivel nacional excepciones a los límites generales en determinados casos y, de hecho, en los últimos años se están implantando en otros Estados miembros de la Unión Europea.

En base a lo expuesto, se considera oportuno modificar algunos aspectos de la regulación de las masas y dimensiones de los vehículos, prevista en el anexo IX del Reglamento General de Vehículos, aprobado por el Real Decreto 2822/1998, de 23 de diciembre. De esta manera se favorece la competitividad y eficiencia tanto de las empresas demandantes de transporte como de las propias empresas transportistas y se avanza en la armonización progresiva de las condiciones de circulación establecidas en nuestro país con respecto a las del resto de países de nuestro entorno.

Así, se incluye una definición para la configuración euro-modular y se permite la circulación de conjuntos de vehículos que adopten dicha configuración con una masa máxima de 60 toneladas y una longitud máxima de 25,25 metros, debiendo en todo caso estar supeditada a la obtención de una autorización expedida por el órgano competente en materia de tráfico, que tendrá en consideración las repercusiones que la circulación de estos conjuntos de vehículos pueden tener en el tráfico y la seguridad vial.

Numerosos estudios, algunos de los cuales han sido recogidos en documentos de la Comisión Europea, han puesto de manifiesto los potenciales beneficios de la circulación de los conjuntos de vehículos en configuración euro-modular, en cuanto a la reducción del tráfico de los vehículos pesados, el ahorro energético, la disminución de emisiones y los menores costes en la actividad del transporte, de gran importancia en el desarrollo de las cadenas logísticas.

Además, en otros países europeos la aplicación de esta medida ha demostrado que no tiene una implicación negativa en los accidentes de tráfico sino que, por el contrario, al disminuir el número de vehículos en circulación necesarios para transportar un determinado volumen de cargas, se produce una reducción correlativa de la exposición al riesgo y, por tanto, se mejora el nivel de seguridad vial.

De acuerdo con lo establecido en el artículo 8.2.d) del texto articulado de la Ley sobre Tráfico, Circulación de Vehículos a Motor y Seguridad Vial, aprobado por el Real Decreto Legislativo 339/1990, de 2 de marzo, se ha sometido a informe del Consejo Superior de Tráfico, Seguridad Vial y Movilidad Sostenible. Así como al trámite de audiencia de conformidad con lo que señala el artículo 24.1.c) de la Ley 50/1997, de 27 de noviembre, del Gobierno.

Esta orden se dicta en uso de la habilitación contenida en la disposición final tercera del Real Decreto 2822/1998, de 23 de diciembre, que faculta a los Ministros del Interior y de Industria, Energía y Turismo para modificar por orden sus anexos, siendo preciso además, en el caso del anexo IX, la conformidad de la Ministra de Fomento.

En su virtud, a propuesta de los Ministros del Interior y de Industria, Energía y Turismo, con la conformidad de la Ministra de Fomento, dispongo:

Artículo único. Modificación del anexo IX del Reglamento General de Vehículos, aprobado por el Real Decreto 2822/1998, de 23 de diciembre.

El anexo IX «Masas y dimensiones», del Reglamento General de Vehículos, aprobado por el Real Decreto 2822/1998, de 23 de diciembre, queda modificado de la siguiente manera:

Uno. Se incorpora el punto 1.23 en el apartado 1 «Definiciones», con el siguiente contenido:

> *«1.23 Configuración euro-modular: Conjunto de vehículos con más de 6 líneas de ejes, cuyos módulos separadamente no superan los límites máximos de masas y dimensiones establecidos en este anexo para el tipo de vehículo que corresponda.»*

Dos. Se incorpora el apartado 6 «Masa máxima autorizada y longitud máxima autorizada de los conjuntos de vehículos en configuración euro-modular».

> *«6. Masa máxima autorizada y longitud máxima autorizada de los conjuntos de vehículos en configuración euro-modular.*
>
> *Se podrá autorizar por el órgano competente en materia de tráfico, previo informe vinculante del titular de vía, la circulación de conjuntos de vehículos en configuración euro-modular, con una masa máxima de hasta 60 toneladas y una longitud máxima de hasta 25,25 metros por un plazo determinado, en las condiciones que se fijen en la autorización. La carga no podrá sobresalir de la proyección en planta del vehículo. Siempre que sea posible, los itinerarios de estos transportes deberán transcurrir por autopistas y autovías.*
>
> *No se podrá conceder la autorización a la que se refiere el párrafo anterior cuando se pretenda realizar transporte de mercancías peligrosas por carretera.»*

Disposición adicional única. Ausencia de aumento de los gastos de personal.

La aplicación de lo dispuesto en esta orden no podrá suponer incremento de dotaciones, ni de retribuciones, ni de otros gastos de personal para la Administración General del Estado.

Disposición derogatoria única. Derogación normativa.

Se derogan cuantas disposiciones de igual o inferior rango se opongan a lo establecido en esta orden.

Disposición final primera. Título competencial.

Esta orden se dicta al amparo de lo dispuesto en el artículo 149.1.21.ª de la Constitución, que atribuye al Estado la competencia exclusiva en materia de tráfico y circulación de vehículos a motor.

Disposición final segunda. Entrada en vigor.

Esta orden entrará en vigor el día siguiente al de su publicación en el «Boletín Oficial del Estado».

Madrid, 18 de diciembre de 2015.–La Vicepresidenta del Gobierno y Ministra de la Presidencia, Soraya Sáenz de Santamaría Antón.

Annex 2 – DGT regulation. April 2016

TEXTO

La Dirección General de Tráfico ha publicado hoy 12 de Abril de 2016 la instrucción en la que se establecen las condiciones y protocolos conforme a los cuales la DGT autorizará la circulación por las carreteras de determinados conjuntos de vehículos en configuración euro modular EMS (European Modular System), más conocidos como megatrucks o megacamiones, tras haber realizado la primera prueba de circulación real, el pasado 2 de marzo, de un conjunto Scania en tráfico abierto, tal y como recogen las fotografías que acompañamos a esta nota de prensa y el video disponible para los medios interesados.

En la prueba se testó un conjunto de semirremolque más remolque con dos tractoras Scania de potencias diferentes, 520 CV y 450 CV, en una ruta que suponía subir el puerto de Somosierra por ambas vertientes.

El trayecto, de ida y vuelta, comenzó en el kilómetro 37 de la A-1 y terminó en el kilómetro 115 de la misma carretera. El diseño de dicha ruta se planificó buscando las condiciones más exigentes, ya que el conjunto afrontó pendientes de hasta el 8% y varios tramos con un 6-7% de desnivel.

El objetivo de este tipo de conjuntos de vehículos es mejorar la eficiencia y la seguridad en el transporte por carretera, a la vez que permitir un funcionamiento más competitivo de los mercados, de acuerdo con el Plan de medidas para el crecimiento, la competitividad y la eficiencia, aprobado con el Consejo de Ministros de 6 de junio de 2014

Esta instrucción, dictada conforme a la Directiva 96/53/CE, desarrolla la Orden MinisterialPRE/2788/2015, de 18 de diciembre por la cual se modificó el anexo IX del Reglamento General de Vehículos.

En dicha Orden Ministerial se introdujo la definición de Configuración Euro-modular para referirse al conjunto de vehículos con más de seis líneas de ejes, cuyos módulos separadamente no superen una masa máxima de 60 toneladas y una longitud de 25,25 metros y se otorga a la Dirección General de Tráfico la potestad para autorizar, previo informe vinculante del titular de la vía, la circulación de este conjunto de vehículos.

La circulación de estos megatrucks ya está permitida en varios países europeos como Países Bajos, Suecia, Finlandia… con resultados satisfactorios.

<u>REQUISITOS PARA SOLICITAR LA AUTORIZACIÓN</u>

Debido a que es un nuevo tipo de conjunto de vehículos circulando por nuestras carreteras, se han establecido los siguientes requisitos para autorizar su circulación:

• El interesado deberá hallarse inscrito en el Registro de Empresas y Actividades de Transporte del Ministerio de Fomento y ser titular del permiso de circulación de los vehículos motrices o contar con una autorización expresa del titular de éste para ser utilizado en conjunto euro-modular.

• Los módulos utilizados deberán constar en el registro de Vehículos de la DGT y deberán cumplir todos los requisitos establecidos en el Reglamento General de Vehículos para su puesta en circulación por vías de uso público.

El conjunto y sus módulos deberán disponer de espejos o detectores de ángulo muerto; sistema de advertencia de abandono de carril o asistencia de mantenimiento en el mismo, sistema electrónico de control de estabilidad y sistema automático de frenado de emergencia, entre otros.

• Respecto a los itinerarios:

> *- Informe favorable de los titulares de las vías en el que se establezca la capacidad física de la misma para soportar el paso de este tipo de conjunto.*
>
> *- Las vías por las que se podrá circular deberán ser autopistas, autovías o carreteras convencionales con calzadas separadas para cada sentido de la circulación. Sólo se podrán incluir vías convencionales de una sola calzada para los dos sentidos de la circulación cuando ello sea necesario para llegar hasta el lugar donde el megatruck realizará las operaciones de carga o descarga debido a que se trate de la única alternativa viable. Los puntos de carga y descarga para los cuales se requiera la circulación por carreteras convencionales de una sola calzada para los dos sentidos, deberán estar situados en polígonos industriales, centros logísticos o áreas similares.*
>
> *- La velocidad a la que podrán circular los euro-modulares es la establecida por el Reglamento de Circulación para los vehículos articulados en función del tipo de vía:*
>
> > *- 90 km/h en autovías y autopistas.*
> >
> > *- 80 km/h en vías convencionales que dispongan de arcén de 1,50 metros o más.*
> >
> > *- Y de 70 km/h en el resto de vías fuera de poblado.*
>
> *- Se suspenderá la circulación de este conjunto de vehículos por carreteras convencionales de una sola calzada cuando existan en el itinerario fenómenos meteorológicos adversos que supongan un riesgo para la circulación y, en todo caso, cuando no exista una visibilidad de 150 metros como mínimo, tanto hacia adelante como hacia atrás o esté activado por la AEMET el aviso meteorológico por riesgo extremo de nivel rojo por viento si el conjunto EMS circula con carga, de nivel naranja si circula sin carga.*

- En vías de una sola calzada para los dos sentidos de la circulación, no podrá adelantar a los vehículos que circulen a más de 45 km/h y deberán llevar alumbrado de cruce encendido o luces de conducción diurna.

- El conjunto de vehículos deberá disponer de dos señales luminosas V-2 que irán situadas en los extremos superiores de la parte frontal posterior del mismo; así como las señales V-6, de vehículo largo, el distintivo V-23, de señalización de su contorno y demás dispositivos de señalización obligatorios para los vehículos dedicados al transporte de mercancías.

- Este tipo de vehículos está sujeto a las restricciones a la circulación que anualmente la DGT establece para los vehículos dedicados al transporte de mercancías en general.

¿DÓNDE PRESENTAR LA SOLICITUD?

Los interesados deberán presentar la solicitud de la autorización especial en las Jefaturas Provinciales o locales de Tráfico. En los próximos meses estará disponible la aplicación informática que permita la gestión automatizada de la misma.

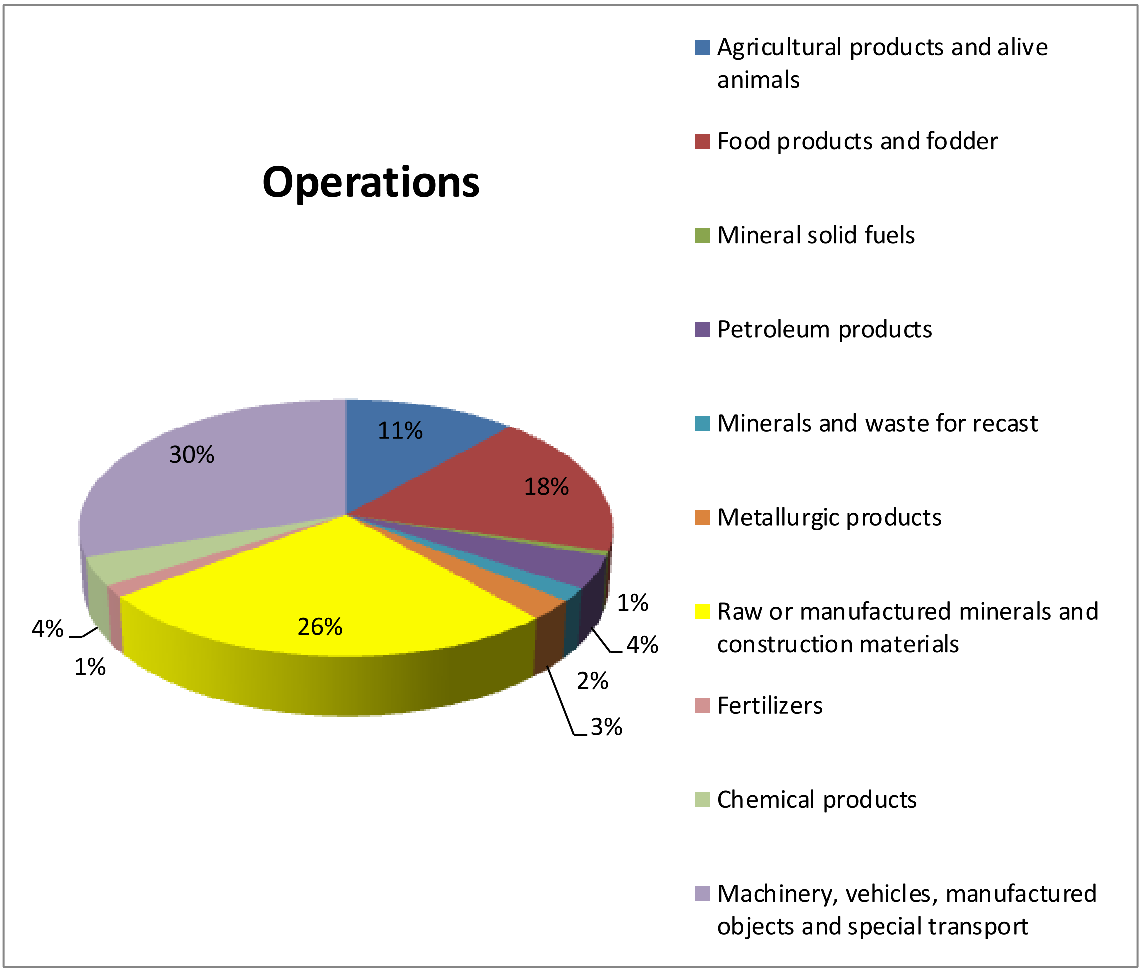
Las autorizaciones se concederán por un plazo máximo de un año, salvo que algún titular de la vía emita un informe de vigencia inferior, en cuyo caso, el plazo de la autorización será el mismo que el informe de menor vigencia.

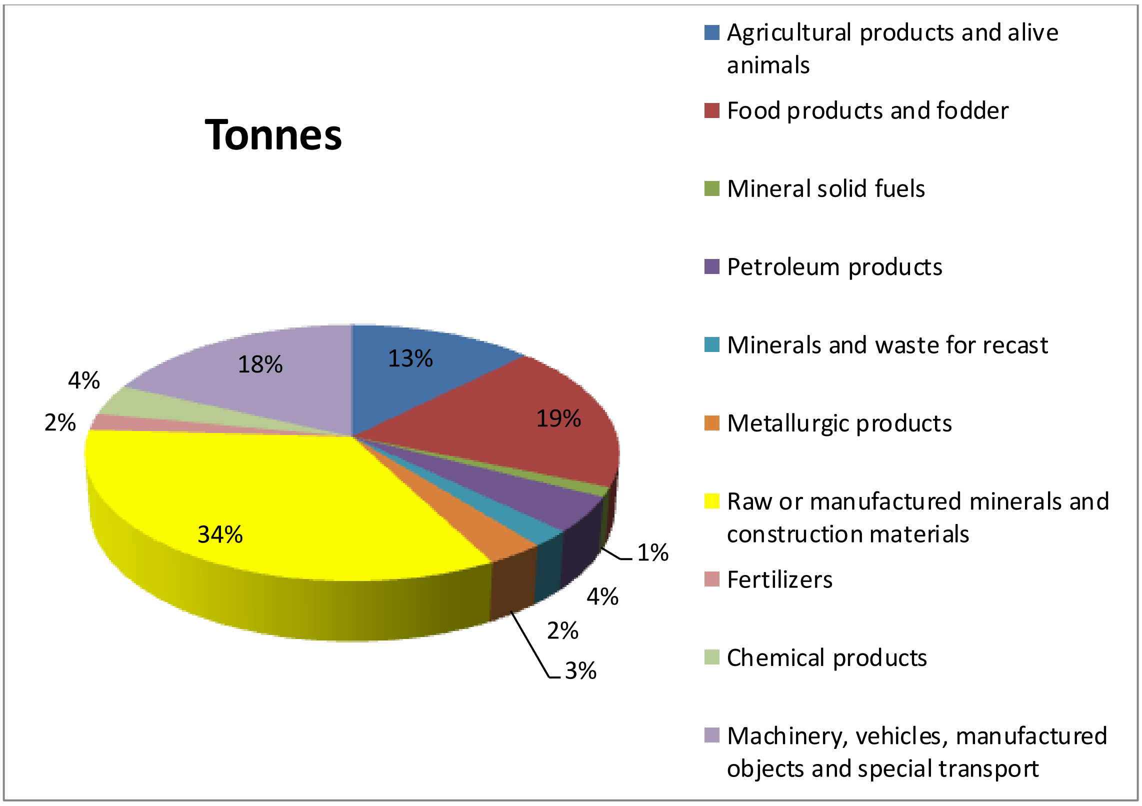
En los tres meses anteriores al fin de su validez, se podrá solicitar la prórroga de la autorización siempre y cuando no varíe ningún dato de la misma.

Mientras la autorización esté vigente, el número de circulaciones no estará limitado, pero el titular tiene la obligación de comunicar por correo electrónico a la DGT los viajes realizados, indicando el número de autorización concedido, fecha y hora de inicio y final de itinerario y longitud del mismo. En breve, Tráfico lanzará una aplicación para que los euro-modulares sus datos de geo-posicionamiento telemáticamente.

Annex 3 – Tonnes transported per type of good

Type of good	Operations	Tonnes (thousands)	Tn-km (millions)
TOTAL	**178.369.381**	**1.258.749**	**209.387**
Agricultural products and alive animals	11.729.842	158.534	40.187
Food products and fodder	18.120.014	234.534	48.380
Mineral solid fuels	608.349	15.433	1.114
Petroleum products	4.163.573	57.579	5.095
Minerals and waste for recast	1.706.749	26.717	3.371
Metallurgic products	2.647.588	38.720	10.656
Raw or manufactured minerals and construction materials	26.488.584	423.523	22.346
Fertilizers	1.496.736	26.840	3.458
Chemical products	3.660.869	48.801	13.183
Machinery, vehicles, manufactured objects and special transport	30.603.451	228.069	61.597
Empty operations	77.143.626	-	-


Operations
Agricultural products and alive animals
Food products and fodder
Mineral solid fuels
Petroleum products
Minerals and waste for recast
Metallurgic products
Raw or manufactured minerals and construction materials
Fertilizers
Chemical products
Machinery, vehicles, manufactured objects and special transport
11%
18%
1%
4%
2%
3%
26%
1%
4%
30%


Tonnes
Agricultural products and alive animals
Food products and fodder
Mineral solid fuels
Petroleum products
Minerals and waste for recast
Metallurgic products
Raw or manufactured minerals and construction materials
Fertilizers
Chemical products
Machinery, vehicles, manufactured objects and special transport
13%
19%
1%
4%
2%
3%
34%
2%
4%
18%

Annex 4 – Calculations for CBA

Costs:

Annual amortization costs per regular truck per unit:

$$A = \frac{C - R - T}{t} = \frac{130.000 + 40.000 - 0,2 * (130.000 + 40.000) - 12 * 700}{8} = 15.950,00€$$

$$j = (1 + 0,02)^5 = 1,11$$

$$F = \frac{\left(n \cdot \frac{L \cdot i \cdot j}{j - 1}\right) - L}{t} = \frac{\left(5 \cdot \frac{0,7 \cdot (170.000) \cdot 0,02 \cdot 1,11}{1,11 - 1}\right) - 0,7 \cdot (170.000)}{8} = 923,52€$$

Annual amortization costs per MegaTruck per unit:

$$A = \frac{C - R - T}{t} = \frac{195.000 + 65.000 - 0,2 * (195.000 + 65.000) - 16 * 700}{8} = 24.600,00€$$

$$j = (1 + 0,02)^7 = 1,15$$

$$F = \frac{\left(n \cdot \frac{L \cdot i \cdot j}{j - 1}\right) - L}{t} = \frac{\left(5 \cdot \frac{0,7 \cdot (260.000) \cdot 0,02 \cdot 1,15}{1,15 - 1}\right) - 0,7 \cdot (260.00)}{8} = 1.895,77€$$

CBA for different options:

Valencia - Madrid

Valencia - Madrid		
Annual demand	1.110.000	tonnes
Distance	368	kilometres

REGULAR TRUCK

Number of required operations	44.400
TOTAL NUMBER OF KILOMETERS	16.339.200
Number of trucks	160,19
NUMBER OF REGULAR TRUCKS	161
Amortization costs	3.190.000 €
Financing costs	184.704 €
Operational costs	12.923.055 €
Total	16.297.759 €

discount rate	5,50	%
Lifetime of each truck	8,00	years
NPV	103.239.227 €	

MEGATRUCK

Number of required operations	28.462	
TOTAL NUMBER OF KILOMETERS	10.473.846	
Number of trucks	102,68	
NUMBER OF MEGATRUCKS	103	
Amortization costs	2.533.800 €	€
Financing costs	195.264 €	€
Operational costs	10.353.695 €	€
Total	13.082.760 €	

discount rate	5,50	%
Lifetime of each MegaTruck	8,00	years
NPV	82.873.605 €	
% of Savings	19,73%	

Socio - economical analysis

REGULAR TRUCK

Monetary value for emissions 0,045 €/kg CO_2

Maintenance costs	1.247,52	€
Emissions	141,68	l
	374,04	€/kg CO_2
Total emissions	60.219,67	€/kg CO_2
	2.709,89 €	
NPV maintenance costs	7.902,50 €	
NPV emission costs	17.165,95 €	

MEGATRUCK

Maintenance costs	1.869,44	€
Emissions	162,93	l
	430,14	€/kg CO_2
Total emissions	44.304,47	€/kg CO_2
	1.993,70 €	
NPV maintenance costs	11.842,09 €	
NPV emission costs	12.629,23 €	

ΔMaintenance costs	3.939,59 €
ΔEmissions	-4.536,71 €
B/C	-1,15156917

CBA for 85% - 15% (cargo trips – empty trips) in regular trucks and 60% - 40% (cargo trips – empty trips) in MegaTrucks:

Barcelona - Madrid	
Annual demand	**810.000 tonnes**
Distance	**627 kilometres**

REGULAR TRUCK

Number of required operations	32.400
TOTAL NUMBER OF KILOMETERS	20.314.800
Number of trucks	199,16

NUMBER OF REGULAR TRUCKS	200

Amortization costs	3.190.000 €
Financing costs	184.704 €
Operational costs	16.067.449 €
Total	19.442.153 €

discount rate	5,50	%
Lifetime of each truck	8,00	years
NPV	123.157.604 €	

MEGATRUCK

Number of required operations	20.769
TOTAL NUMBER OF KILOMETERS	13.022.308
Number of trucks	180,87

NUMBER OF MEGATRUCKS	181

Amortization costs	4.452.600 €	€
Financing costs	343.134 €	€
Operational costs	12.872.922 €	€
Total	17.668.657 €	

discount rate	5,50	%
Lifetime of each MegaTruck	8,00	years
NPV	111.923.271 €	

% of Savings	9,12%

Socio - economical analysis

REGULAR TRUCK

Monetary value for emissions 0,045 €/kg CO_2

Maintenance costs	2.125,53	€
Emissions	241,40	l
	637,28	€/kg CO_2
Total emissions	127.456,56	€/kg CO_2
	5.735,55 €	

NPV maintenance costs	13.464,31 €
NPV emission costs	36.332,19 €

MEGATRUCK

Maintenance costs	3.185,16	€
Emissions	277,60	l
	732,88	€/kg CO_2
Total emissions	132.650,41	€/kg CO_2
	5.969,27 €	

NPV maintenance costs	20.176,61 €
NPV emission costs	37.812,73 €

ΔMaintenance costs	6.712,30 €
ΔEmissions	1.480,54 €
B/C	0,22057083

CBA for 85% - 15% (cargo trips – empty trips) in regular trucks and 50% - 50% (cargo trips – empty trips) in MegaTrucks:

Barcelona - Madrid		
Annual demand	810.000	tonnes
Distance	627	kilometres

REGULAR TRUCK

Number of required operations	32.400
TOTAL NUMBER OF KILOMETERS	20.314.800
Number of trucks	199,16

NUMBER OF REGULAR TRUCKS	200

Amortization costs	3.190.000 €
Financing costs	184.704 €
Operational costs	16.067.449 €
Total	19.442.153 €

discount rate	5,50	%
Lifetime of each truck	8,00	years
NPV	123.157.604 €	

MEGATRUCK

Number of required operations	20.769
TOTAL NUMBER OF KILOMETERS	13.022.308
Number of trucks	217,04

NUMBER OF MEGATRUCKS	218

Amortization costs	5.362.800 €	€
Financing costs	413.278 €	€
Operational costs	12.872.922 €	€
Total	18.649.000 €	

discount rate	5,50	%
Lifetime of each MegaTruck	8,00	years
NPV	118.133.322 €	

% of Savings	4,08%

Socio - economical analysis

REGULAR TRUCK

Monetary value for emissions 0,045 €/kg CO_2

Maintenance costs	2.125,53	€
Emissions	241,40	l
	637,28	€/kg CO_2
Total emissions	127.456,56	€/kg CO_2
	5.735,55 €	

NPV maintenance costs	13.464,31 €
NPV emission costs	36.332,19 €

MEGATRUCK

Maintenance costs	3.185,16	€
Emissions	277,60	l
	732,88	€/kg CO_2
Total emissions	159.766,80	€/kg CO_2
	7.189,51 €	

NPV maintenance costs	20.176,61 €
NPV emission costs	45.542,40 €

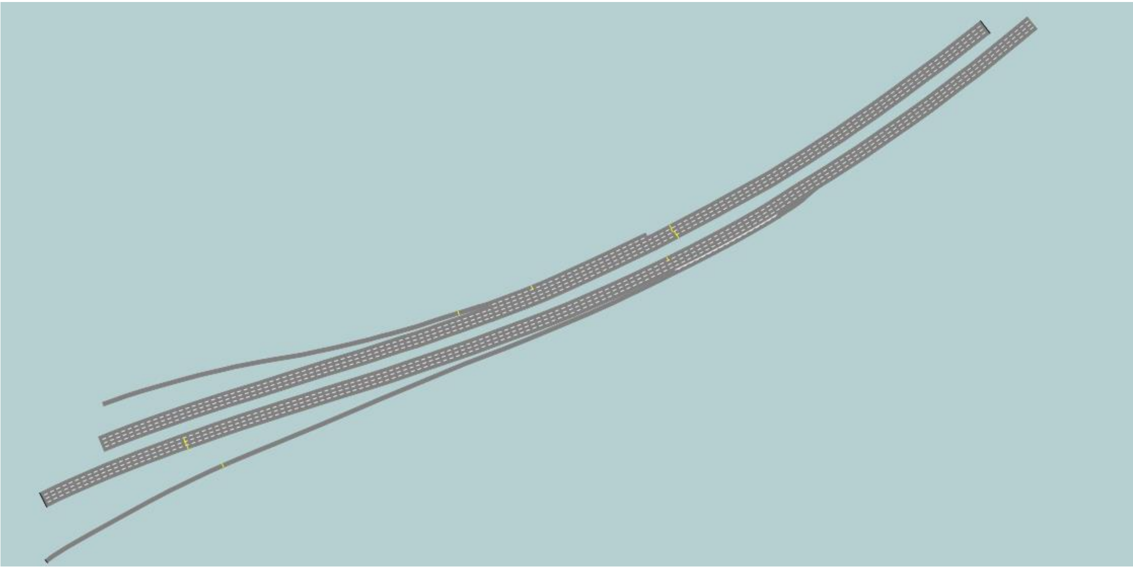
ΔMaintenance costs	6.712,30 €
ΔEmissions	9.210,21 €
B/C	1,37214

Annex 5 – Screenshots of the simulation

Definition of links

Coun	No	Name	LinkBehavType	DisplayType	Level	NumLanes	Length2D
1	1	Autopista direcció la Jonquera	2: Right-side rule (motorized)	1: Road gray	1: Base	4	592,955
2	2	On ramp la Jonquera	2: Right-side rule (motorized)	1: Road gray	1: Base	1	610,350
3	3	Autopista direcció Barcelona Tram 1	2: Right-side rule (motorized)	1: Road gray	1: Base	4	351,657
4	4	Autopista direcció Barcelona Tram 2	2: Right-side rule (motorized)	1: Road gray	1: Base	5	153,772
5	5	Autopista direcció Barcelona Tram 3	2: Right-side rule (motorized)	1: Road gray	1: Base	4	362,674
6	6	Off ramp Barcelona	2: Right-side rule (motorized)	1: Road gray	1: Base	1	344,527
7	7	Autopista direcció la Jonquera Tram	2: Right-side rule (motorized)	1: Road gray	1: Base	5	104,590
8	8	Autopista direcció la Jonquera Tram 3	2: Right-side rule (motorized)	1: Road gray	1: Base	4	277,941
9	10000	connector on ramp 1	2: Right-side rule (motorized)	1: Road gray		1	2,683
10	10001	connector la Jonquera 1 2	2: Right-side rule (motorized)	1: Road gray		4	2,223
11	10002	connector Barcelona 1 2	2: Right-side rule (motorized)	1: Road gray		4	2,844
12	10003	connector Barcelona 2 3	2: Right-side rule (motorized)	1: Road gray		4	1,786
13	10004	connector Barcelona 2 off	2: Right-side rule (motorized)	1: Road gray		1	8,543
14	10005	connector la Jonquera 2 3	2: Right-side rule (motorized)	1: Road gray		4	2,833

Details of the network

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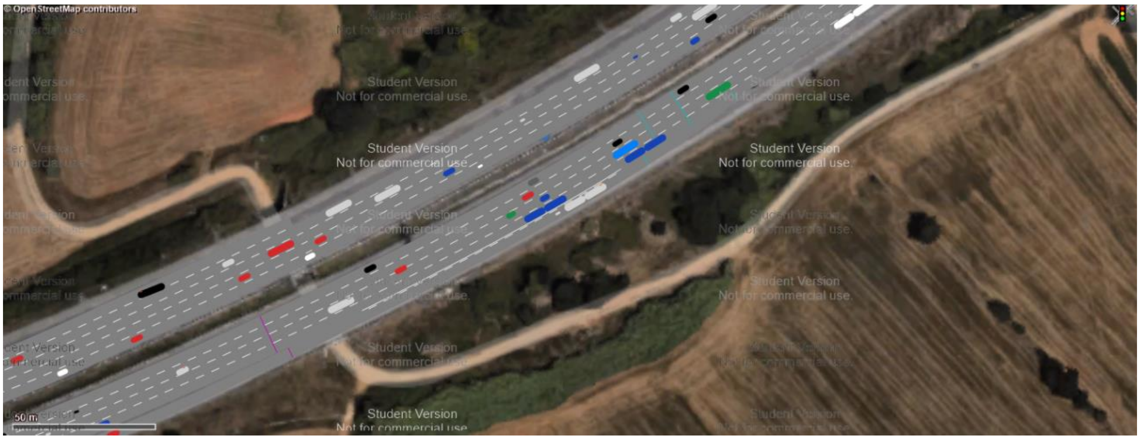
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Student Version
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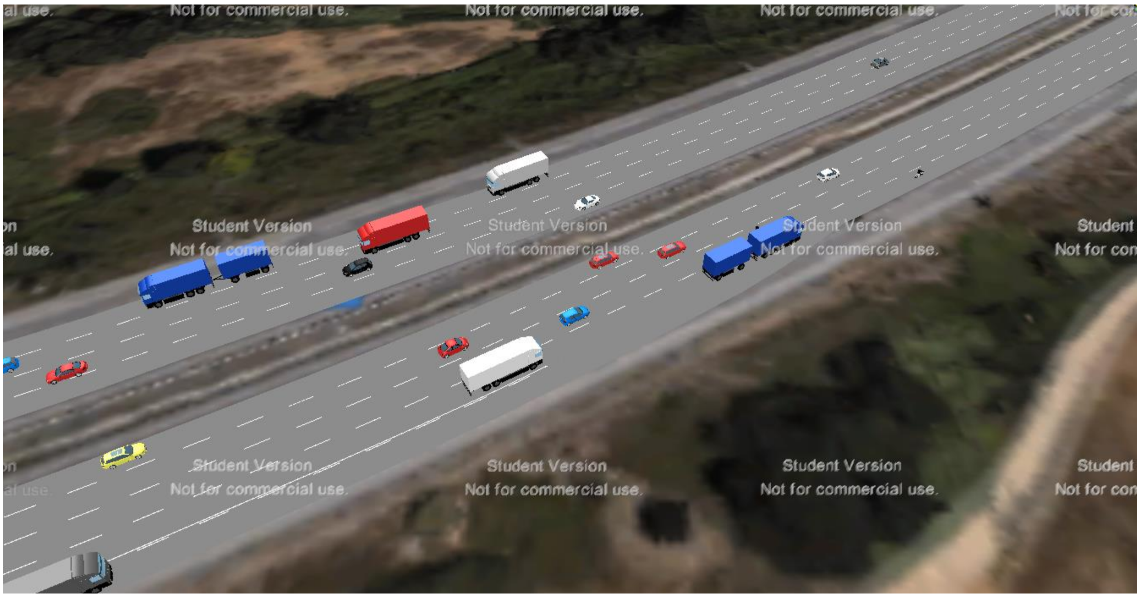
Student Version
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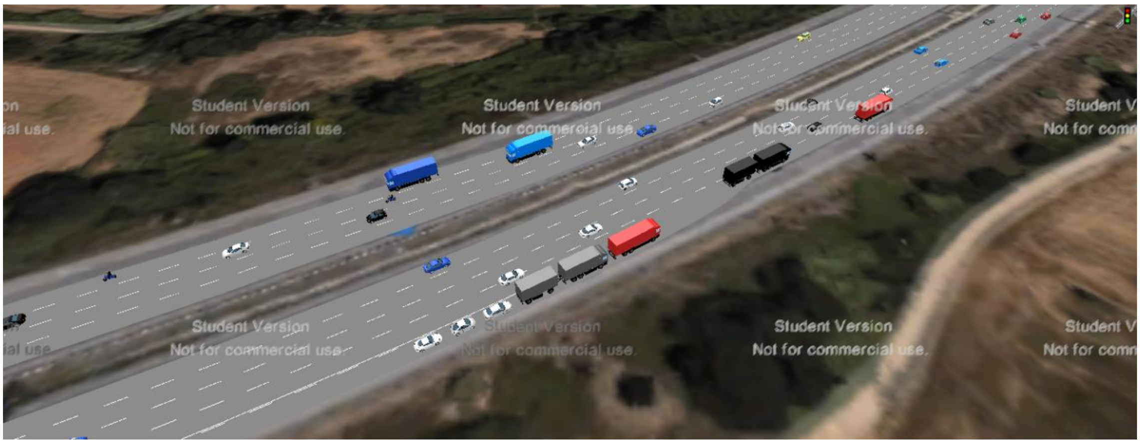
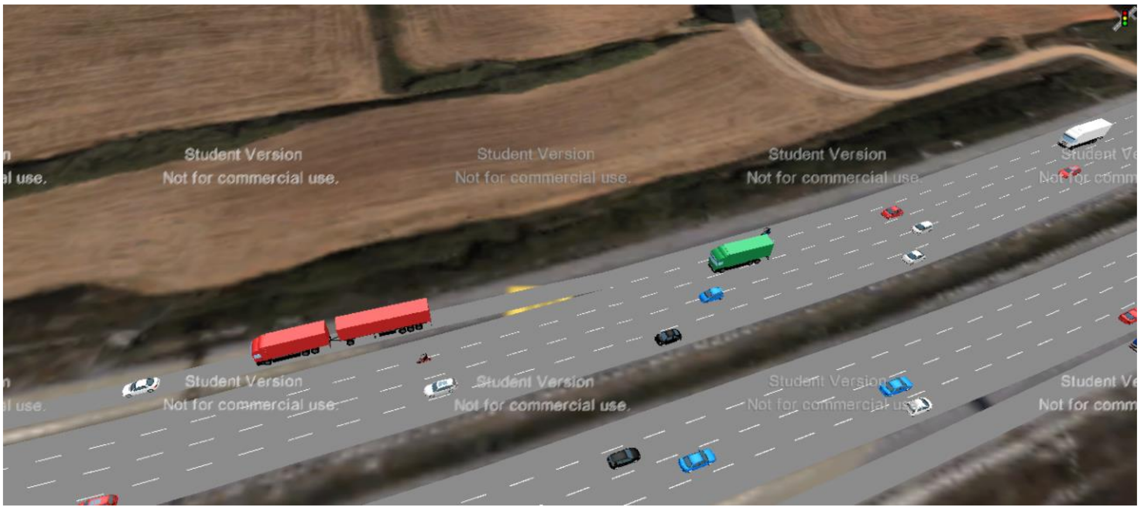

Student Version
Not for commercial use.


Student Version
Not for commercial use.

Desired speed Distribution for the vehicles classes:

Desired Speed Decisions / Desired Speed Distributions By Vehicle Class

Select layout... Desired speed distribu

Coun	No	Name	Lane	Pos	TimeFrom	TimeTo	DesSpeedDistr(10)	DesSpeedDistr(20)	DesSpeedDistr(70	DesSpeedDistr(30)	DesSpeedDistr(40)	DesSpeedDistr(50)	DesSpee
1	1		1: Autopista direcció la Jonquera - 1	136,160	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				
2	2		1: Autopista direcció la Jonquera - 2	[illegible]	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
3	3		1: Autopista direcció la Jonquera - 3	135,612	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
4	5		3: Autopista direcció Barcelona Tram 1 -	330,785	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				
5	6		3: Autopista direcció Barcelona Tram 1 -	331,116	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
6	7		3: Autopista direcció Barcelona Tram 1 -	329,547	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
7	8		3: Autopista direcció Barcelona Tram 1 -	329,111	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
8	15		2: On ramp la Jonquera - 1	177,834	0	99999	90: 90 km/h	70: 70 km/h	70: 70 km/h				
9	16		6: Off ramp Barcelona - 1	19,818	0	99999	90: 90 km/h	70: 70 km/h	70: 70 km/h				
10	17		4: Autopista direcció Barcelona Tram 2 -	111,868	0	99999	90: 90 km/h	70: 70 km/h	70: 70 km/h				
11	18		4: Autopista direcció Barcelona Tram 2 -	111,501	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				
12	19		4: Autopista direcció Barcelona Tram 2 -	111,383	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
13	20		4: Autopista direcció Barcelona Tram 2 -	111,266	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
14	21		4: Autopista direcció Barcelona Tram 2 -	110,540	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
15	22		5: Autopista direcció Barcelona Tram 3 -	21,166	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				
16	23		5: Autopista direcció Barcelona Tram 3 -	20,771	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
17	24		5: Autopista direcció Barcelona Tram 3 -	20,847	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
18	25		5: Autopista direcció Barcelona Tram 3 -	20,579	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
19	26		7: Autopista direcció la Jonquera Tram 2	39,073	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
20	27		7: Autopista direcció la Jonquera Tram 2	39,160	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
21	28		7: Autopista direcció la Jonquera Tram 2	40,410	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
22	29		7: Autopista direcció la Jonquera Tram 2	40,834	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				
23	30		8: Autopista direcció la Jonquera Tram 3	11,771	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
24	31		8: Autopista direcció la Jonquera Tram 3	12,671	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
25	32		8: Autopista direcció la Jonquera Tram 3	11,827	0	99999	120: 120 km/h	90: 90 km/h	90: 90 km/h				
26	33		8: Autopista direcció la Jonquera Tram 3	11,799	0	99999	100: 100 km/h	80: 80 km/h	80: 80 km/h				

Annex 6 – Example of a Text outcome file from VISSIM 8 (.fzp)

$VISION
* File: C:\Users\Ricard\Escola\UNI\4t\TFG\Simulation\Simulació.inpx
* Comment:
* Date: 18/05/2016 22:45:01
* PTV Vissim: 8.00 [02]
*
* Table: Vehicles In Network
*
* SIMSEC: SimSec, Simulation second [s]
* NO: No, Number
* LANE\LINK\NO: Lane\Link\No, Lane\Link\Number
* LANE\INDEX: Lane\Index, Lane\Index
* POS: Pos, Position [m]
* POSLAT: PosLat, Position (lateral)
* LNCHG: LnChg, Lane change
* SPEED: Speed, Speed [km/h]
* VEHTYPE: VehType, Vehicle type
* ACCELERATION: Acceleration, Acceleration [m/s2]
* HDWY: Hdwy, Headway [m]
* SimSec; No; Lane\Link\No; Lane\Index; Pos; PosLat; LnChg; Speed; VehType; Acceleration; Hdwy
*
$VEHICLE:SIMSEC;NO;LANE\LINK\NO;LANE\INDEX;POS;POSLAT;LNCHG;SPEED;VEHTYPE;ACCELERATION;HDWY
0.20;1;1;1;2.14;0.50;None;115.09;200;0.00;0.00
0.30;1;1;1;5.34;0.50;None;115.09;200;0.00;0.00
0.40;1;1;1;8.53;0.50;None;115.09;200;0.00;0.00
0.40;2;1;2;3.34;0.50;None;121.38;200;0.00;0.00
0.50;1;1;1;11.73;0.50;None;115.09;200;0.00;0.00
0.50;2;1;2;6.72;0.50;None;121.38;200;0.00;0.00
0.60;1;1;1;14.93;0.50;None;115.09;200;0.00;0.00
0.60;2;1;2;10.09;0.50;None;121.38;200;0.00;0.00
0.70;1;1;1;18.12;0.50;None;115.09;200;0.00;0.00
0.70;2;1;2;13.46;0.50;None;121.38;200;0.00;0.00
0.70;3;3;1;2.39;0.50;None;110.51;100;0.00;0.00
0.70;4;3;2;1.15;0.50;None;107.47;100;0.00;0.00
0.80;1;1;1;21.32;0.50;None;115.09;200;0.00;0.00
0.80;2;1;2;16.83;0.50;None;121.38;200;0.00;0.00
0.80;3;3;1;5.46;0.50;None;110.51;100;0.00;0.00
0.80;4;3;2;4.14;0.50;None;107.47;100;0.00;0.00
0.90;1;1;1;24.52;0.50;None;115.09;200;0.00;0.00
0.90;2;1;2;20.20;0.50;None;121.38;200;0.00;0.00
0.90;3;3;1;8.53;0.50;None;110.51;100;0.00;0.00
0.90;4;3;2;7.12;0.50;None;107.47;100;0.00;0.00
1.00;1;1;1;27.71;0.50;None;115.09;200;0.00;0.00
1.00;2;1;2;23.57;0.50;None;121.38;200;0.00;0.00
1.00;3;3;1;11.60;0.50;None;110.51;100;0.00;0.00
1.00;4;3;2;10.11;0.50;None;107.47;100;0.00;0.00

1.10;1;1;1;30.91;0.50;None;115.09;200;0.00;0.00
1.10;2;1;2;26.94;0.50;None;121.38;200;0.00;0.00
1.10;3;3;1;14.67;0.50;None;110.51;100;0.00;0.00
1.10;4;3;2;13.09;0.50;None;107.47;100;0.00;0.00
1.20;1;1;1;34.11;0.50;None;115.09;200;0.00;0.00
1.20;2;1;2;30.32;0.50;None;121.38;200;0.00;0.00
1.20;3;3;1;17.74;0.50;None;110.51;100;0.00;0.00
1.20;4;3;2;16.08;0.50;None;107.47;100;0.00;0.00
1.30;1;1;1;37.31;0.50;None;115.09;200;0.00;0.00
1.30;2;1;2;33.69;0.50;None;121.38;200;0.00;0.00
1.30;3;3;1;20.81;0.50;None;110.51;100;0.00;0.00
1.30;4;3;2;19.06;0.50;None;107.47;100;0.00;0.00
1.40;1;1;1;40.50;0.50;None;115.09;200;0.00;0.00
1.40;2;1;2;37.06;0.50;None;121.38;200;0.00;0.00
1.40;3;3;1;23.88;0.50;None;110.51;100;0.00;0.00
1.40;4;3;2;22.05;0.50;None;107.47;100;0.00;0.00
1.40;5;3;3;1.96;0.50;None;125.82;630;0.00;0.00
1.50;1;1;1;43.70;0.50;None;115.09;200;0.00;0.00
1.50;2;1;2;40.43;0.50;None;121.38;200;0.00;0.00
1.50;3;3;1;26.95;0.50;None;110.51;100;0.00;0.00
1.50;4;3;2;25.03;0.50;None;107.47;100;0.00;0.00
1.50;5;3;3;5.46;0.50;None;125.82;630;0.00;0.00
1.60;1;1;1;46.90;0.50;None;115.09;200;0.00;0.00
1.60;2;1;2;43.80;0.50;None;121.38;200;0.00;0.00
1.60;3;3;1;30.02;0.50;None;110.51;100;0.00;0.00
1.60;4;3;2;28.02;0.50;None;107.47;100;0.00;0.00
1.60;5;3;3;8.95;0.50;None;125.82;630;0.00;0.00
1.70;1;1;1;50.09;0.50;None;115.09;200;0.00;0.00
1.70;2;1;2;47.17;0.50;None;121.38;200;0.00;0.00
1.70;3;3;1;33.09;0.50;None;110.51;100;0.00;0.00
1.70;4;3;2;31.00;0.50;None;107.47;100;0.00;0.00
1.70;5;3;3;12.45;0.50;None;125.82;630;0.00;0.00
1.70;6;1;1;1.79;0.50;None;113.87;200;0.00;48.27
1.80;1;1;1;53.29;0.50;None;115.09;200;0.00;0.00
1.80;2;1;2;50.55;0.50;None;121.38;200;0.00;0.00
1.80;3;3;1;36.16;0.50;None;110.51;100;0.00;0.00
1.80;4;3;2;33.99;0.50;None;107.47;100;0.00;0.00
1.80;5;3;3;15.94;0.50;None;125.82;630;0.00;0.00
1.80;6;1;1;4.95;0.50;None;113.87;200;0.00;48.30
1.90;1;1;1;56.49;0.50;None;115.09;200;0.00;0.00
1.90;2;1;2;53.92;0.50;None;121.38;200;0.00;0.00
1.90;3;3;1;39.23;0.50;None;110.51;100;0.00;0.00

*This annex has been cut. The original file has around 700.000 lines and a weight of 30Mb.

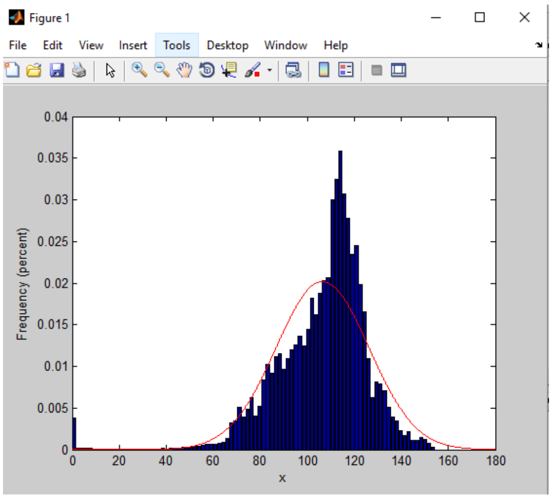
Annex 7 – MatLab Script

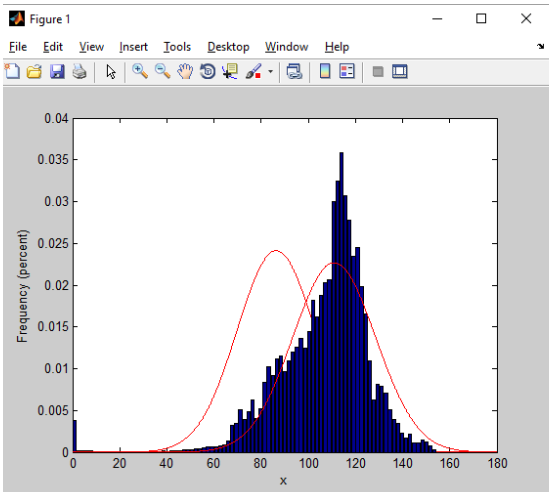
```
close all;

%%
% Delete rows where colum 11 is zero
%Set condition ( select all rows where col 11 is 0)
TF1 = A(:,11)==0;
TF2 = A(:,10)<-2;
%Copy A to B and delete the selected rows
B = A;
B(TF1 | TF2,:) = [];
data = B;
%%
%Plot speed of cars
figure(1);
%Calculate the histogram
numOfBins = 90;
[histFreq, histXout] = hist(data(:,8), numOfBins);
figure(1);
bar(histXout, histFreq/trapz(histXout,histFreq));
%Calculate the mean and sigma of data
selector = data(:,9)==610;
[mu,sigma] = normfit(data(:,8));
X = 0:0.1:180;
Y = normpdf(X,mu,sigma);
speed_text = sprintf('Speed Mean: %f  var: %f', mu, sigma)
%Plot the norm distribution of data
hold on;
plot(X, Y,'r')
%Set x,y lables
xlabel('x');
ylabel('Frequency (percent)');

%%
%Car type plot
% [uv,~,idx] = unique(data(:,2));
% n = accumarray(idx(:),1);
%
% lables = {}
% for i = 1:1:size(uv,1);
%     lables{i} = sprintf('Type: %i',uv(i));
% end
%
% pie(n)
% legend(lables,'Location','southoutside','Orientation','horizontal')
figure(2);
cars = [0.1,0.2,0.7,0.1]
% car_types = [0,100,200]
lables = {'Car','HGV','Conventional','Motorbike'}

% for i = 1:1:size(car_types,2);
%     lables{i} = sprintf('Type: %i',car_types(i));
% end
pie(cars)
legend(lables,'Location','southoutside','Orientation','horizontal')

%%
%Plot headways
```

```
%Calculate the histogram
figure(3);
numOfBins = 100;

selector = data(:,9)==610;

[histFreq, histXout] = hist(data(:,11), numOfBins);

[mu,sigma] = normfit(data(:,11));
speed_text = sprintf('Headway Mean: %f  var: %f', mu, sigma)
bar(histXout, histFreq/trapz(histXout,histFreq));

%%
%Plot number of lane changes
figure(4);
selector = data(:,9)==610;
[uv,~,idx] = unique(data(:,7));
n = accumarray(idx(:),1);

bar(uv,n);
n
for i1=1:numel(n)
    text(uv(i1),n(i1),num2str(n(i1),'%0.2f'),...
               'HorizontalAlignment','center',...
               'VerticalAlignment','bottom')
end

%%
%Acceleration
figure(5);
numOfBins = 100;
[histFreq, histXout] = hist(data(:,10), numOfBins);
bar(histXout, histFreq/trapz(histXout,histFreq));
[mu,sigma] = normfit(data(:,10));
speed_text = sprintf('Acceleration Mean: %f  var: %f', mu, sigma)
%%
%Calculate average speed of each car
% [car_id,~,idx] = unique(data(:,2));
%
%
% for i = 1:1:car_id
%     %Set condition ( select all rows where col 11 is 0)
%     TF1 = A(:,2)~=i;
%     %Copy A to B and delete the selected rows
%     B = A;
%     B(TF1 | TF2,:) = [];
%     sum(B(:,10))
% end
%%Lateral position

[mu,sigma] = normfit(data(:,6));
position = sprintf('Lateral position Mean: %f  var: %f', mu, sigma)

number_cars = size(data,1)
cars_middle = sum(data(:,6) == 0.5)
cars_right = sum(data(:,6) > 0.5)
cars_left = sum(data(:,6) < 0.5)
```

Annex 8 – Lane restriction results

Speed Distribution: a) with cars, b) with cars and MegaTrucks

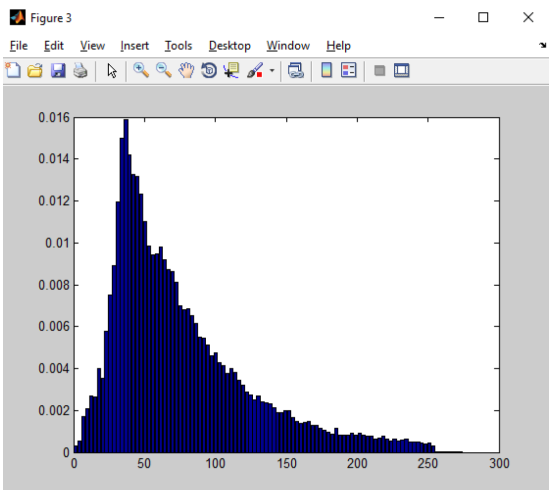




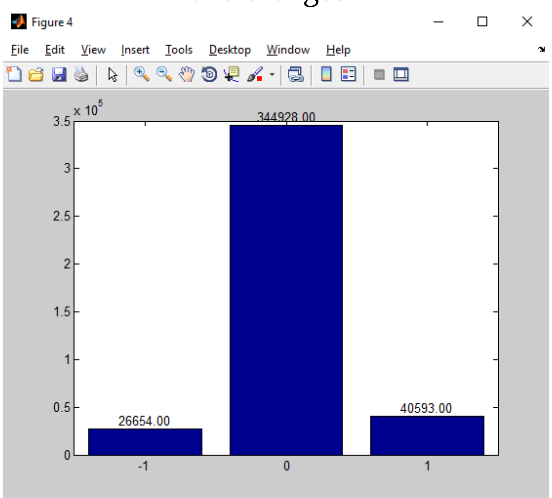
a

b

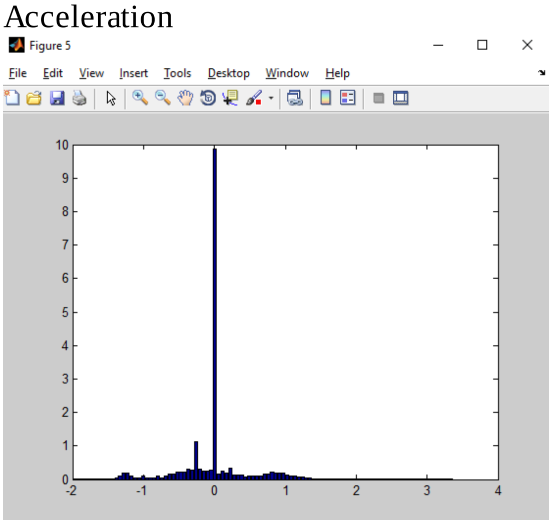
Headway profile



Lane changes



Acceleration



	Scenatio 3 (30% MT) lane restriction			
	General	Car	Truck	MegaTruck
Speed mean (km/h)	106,48	110,98	92,51	86,36
Speed variace (km/h)	19,77	17,58	15,29	16,53
Headway mean (m)	75,89	79,23	65,35	63,20
Headway variance (m)	49,08	51,57	37,27	35,75
Left changes	26.654,00	24.220	1.203	50
Right changes	40.593,00	35.106	2.666	73
Acceleration mean (m/s^2)	-0,02	0,02	-0,19	-0,18
Acceleration variance(m/s^2)	0,49	0,48	0,52	0,50